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TRANSPORTATION LABORATORY
RESEARCH REPORT

THE PRECISION OF SELECTED AGGREGATE TEST METHODS

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16. ABSTRACT

Precision statements for the following test methods are presented: Sieve Analysis, % Crushed Particles, L. A. Rattler, Sand Equivalent, Cleanness Value, Durability Index and R-value. The interlaboratory correlation program pilot study from which these statements were derived, is briefly discussed. Relative amounts of general error types such as between operator and between laboratory are given for each test method, and possible causes are discussed. Laboratory performance is shown through the use of scatter diagrams and ranking summaries. Specific recommendations for improving test precision are given.

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DEPARTMENT OF TRANSPORTATION
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TRANSPORTATION LABORATORY

June 1975

FHWA No. F-4-20
TL No. 631153

Mr. R. J. Datel
Chief Engineer

Dear Sir:

I have approved and now submit for your information this interim research project report titled:

PRECISION OF
SELECTED AGGREGATE TEST METHODS

Study made by . . . . General Services Branch

Under the Supervision of . . . . W. H. Ames, P.E.

Principal Investigator
and Author . . . . Paul E. Benson

Co-Investigators . . . . Richard R. Trimble, P.E.
Carl R. Sundquist, P.E.

Very truly yours,

George A Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

ACKNOWLEDGEMENTS

Without the hard work of the numerous laboratory technicians throughout the State, this report would not have been possible. The author wishes to thank the Pavement Branch of the Office of Transportation Laboratory, particularly Mr. Thomas Whitney, for performing the cumbersome and tedious job of splitting the bulky samples into manageable and homogeneous sub-samples. Also, for diligently carrying out the extensive testing program, a special thanks go to the laboratory personnel in each of the 11 transportation districts who participated in the project.

This project was conducted in cooperation with the Federal Highway Administration under Agreement No. F-4-20. The contents of this report reflect the views of the Office of Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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INTRODUCTION

Over the years a number of valuable test methods have been developed for judging the quality of aggregate used in portland cement concrete, asphalt concrete, base and subbase construction. When applied properly, these tests have consistently been used to accept material of adequate quality and reject material of inferior quality. Until this time, however, only a minimum effort has been made to measure and improve the precision of these tests. Active calibration and certification programs have sought to identify testing errors so that they might be reduced. However, these programs have been handicapped by lack of knowledge about the magnitude and source of these errors. An integrated method for continually monitoring test precision and evaluating laboratory and operator performance is needed.

This report summarizes the results of a yearlong pilot study which measured the precision of a number of aggregate test methods, quantified the sources of testing error, and evaluated laboratory performance. The test methods studied were: Coarse and Fine Sieve Analysis, R-value, L. A. Rattler Abrasion, Fine Durability, Coarse Durability, Cleanness Value, Sand Equivalent, and Percent Crushed Particles. The precision statements for these test methods are considered preliminary and will be revised for the final report as further data from our ongoing correlation program becomes available.

The results contained herein were analyzed by a series of computer programs developed especially for this study. These programs are fully explained in another report issued by the California Department of Transportation entitled "Development of a Correlation Program" (2).

To clarify some of the conclusions reached in this report, a brief discussion of the concepts of precision and testing error is necessary. California has adopted a method of reporting test precision recommended in ASTM Designation: C670-71T. This is based on a statistical parameter called the Difference Two-Sigma Limit (D2S). ASTM uses the D2S limit to form two different types of precision statements:

(1) Single-Operator Precision - A measure of the greatest difference between two results that would be considered acceptable when properly conducted determinations are made on uniformly prepared portions of material by a competent operator using one set of equipment.

(2) Multilaboratory Precision - A measure of the greatest difference between two results that would be considered acceptable when properly conducted determinations are made by two different operators in different laboratories on uniformly prepared portions of material.

Single-Operator and Multilaboratory Precision Statements are given in this report for each test method studied. The D2S limit is referred to as the "Acceptable Range of Two Results" in these statements. For many of the tests, precision was found to vary significantly according to the range of material tested. The precision statement is given in a tabular form for these test methods. The overall range of material studied for each test method is given also. Precision statements are accurate for this range only, and should not be extrapolated.

Testing error was divided into two general categories for the purposes of this study. The first, systematic error, is composed of errors whose sources are identifiable. For this experiment the identifiable sources of error were between laboratories, between operators in the same laboratory and scale-type error (7).

A large between laboratory error might indicate significant variations from laboratory to laboratory in either technique, environment or equipment. A large between operator error could indicate inadequate training and certification programs at the local level. Scale-type errors are caused by inconsistencies between expected and observed test results from one range of results to another. Significant scale-type errors usually occur in test methods which use different equipment or techniques for each range of material tested. For instance, a set of poorly calibrated standard weights would yield a large scale-type error when weighing objects of varying sizes.

Systematic errors can often be minimized because their causes are usually known. The second type of testing error, residual error, represents the total of all errors not accounted for by the systematic components of operator, laboratory and scale-type effects. Minimizing this type of error can be more difficult. If additional experimentation does not reveal more systematic components of the residual error, the precision of the final result can only be improved by averaging a predetermined number of repeated tests for each test result or by tightening method and equipment tolerances. Before this is done, however, the magnitude of the sample preparation error (a measure of the uniformity of the sample preparation procedure) should be checked. If this error is a large part of the overall residual error, then the actual test precision will be better than indicated and may not need improvement.

Single-operator precision was calculated from the residual error, and as such included the random errors inherent in both the test method and the sample preparation procedure. Multilaboratory precision was derived from a combination of systematic and residual errors, and therefore included effects of laboratory environments, equipment, and operator technique in addition to the residual error.

RECOMMENDATIONS

In the interest of improving the precision of the test methods studied, it is recommended that:

(1) A permanent correlation program similar to the one used in this pilot study be implemented on an annual or semi-annual basis with an annual performance report being issued to the participating laboratories.

(2) More intensive efforts be directed towards Department-wide calibration of Los Angeles Abrasion Testing Machines.

(3) A more uniform training program be implemented for personnel performing the % Crushed Particles Test.

(4) An experiment to determine the effects of temperature and calcium chloride solution concentration on the precision of the Durability Index Test be conducted.

(5) A comprehensive experiment on the R-value Test be conducted to study the effect of test variables on precision, especially the mid-range (20-60) materials.

The relative priorities for implementing these recommendations for each test method should be based on the frequency of testing and the ratio of the testing error to the overall variability of materials, sampling and testing.

FINDINGS AND CONCLUSIONS

I. Sieve Analysis (Test Method No. Calif. 202-G)

The Sieve Analysis Test Method is divided into two parts: a coarse analysis and a fine analysis. Because these are, in effect, two different test methods, their precision was studied separately.

The coarse analysis procedure is used for material retained on the #4 and coarser sieves. Test precision for these sieves was found to be roughly dependent upon the total weight of material passing them. Except for the range of 95 to 99% passing, the greater the weight of material passing a coarse sieve, the less repeatable were its results. Apparently, shaking time became more critical and errors from sieve defects were magnified as a greater weight of material passed through a given sieve. The dependent nature of one sieve result on another makes this impossible to prove, however. The assumption was made for this study that the percent passing a sieve was a reasonably consistent representation of the actual weight of material passing the sieve since sample sizes were fairly uniform from test to test. The relationship between percent passing and repeatability should only be considered a rule of thumb, however, and should not be applied in extreme cases.

Figure 1 shows the pooled within lab standard deviation (a result of both between operator and residual sources of error) plotted against percent passing for all coarse sieve-sample combinations. The least squares linear plot shown, which was not based on 95 to 99% passing results (shown in dashed area), has a coefficient of correlation of 0.49. Table 1 gives the single-operator and multilaboratory precision of the Coarse Sieve Analysis.

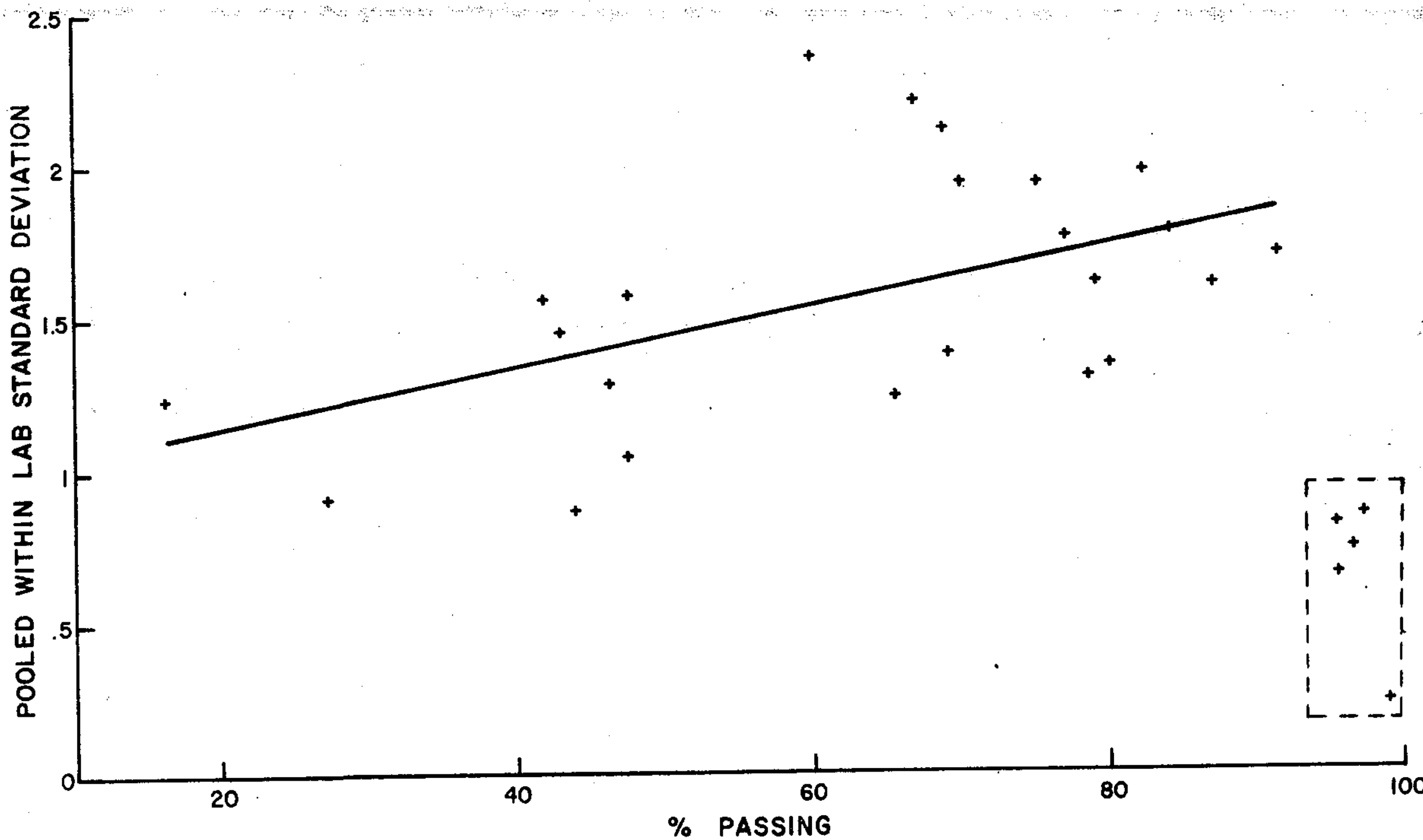

Fig.1 TEST PRECISION VS MATERIAL RANGE
COARSE SIEVE ANALYSIS

TABLE 1

PRECISION STATEMENT TABULATION
COARSE SIEVE ANALYSIS (3/4" THRU #4)

SINGLE-OPERATOR PRECISION

% PASSING	VARIANCE	STANDARD DEVIATION	ACCEPTABLE RANGE OF TWO RESULTS
20	1.09	1.04	3.0
30	1.28	1.13	3.2
40	1.49	1.22	3.5
50	1.72	1.31	3.7
60	1.96	1.40	4.0
70	2.21	1.49	4.2
80	2.48	1.58	4.5
90	2.77	1.66	4.7
1 to 5 & 95 to 99	.56	.75	2.1

MULTILABORATORY PRECISION

% PASSING	VARIANCE	STANDARD DEVIATION	ACCEPTABLE RANGE OF TWO RESULTS
20	1.58	1.26	3.6
30	1.86	1.36	3.9
40	2.16	1.47	4.2
50	2.48	1.58	4.5
60	2.83	1.68	4.8
70	3.20	1.79	5.1
80	3.59	1.89	5.4
90	4.01	2.00	5.7
1 to 5 & 95 to 99	1.17	1.08	3.1

A fine analysis procedure is used for material passing the #4 and finer sieves. This method combines hydraulic and mechanical agitation techniques to gradate the sample and wash out clay and silt particles. Table 2 lists its precision over the range studied.

The fine sieve results are weighted according to the amount of material passing the #4 sieve to yield combined or overall results for sieves #8 through #200. Figure 2 shows the pooled within lab standard deviation plotted against the percent passing for these results. The coefficient of correlation for this linear regression is 0.89. Table 3 summarizes the precision of the Combined Sieve Analysis.

The most dominant source of error for both the Coarse and Fine Sieve Analyses was residual error. It is presumed that the largest part of this error was caused by the inability to accurately split samples into identical sub-samples.

Generally speaking, the Department-wide precision of the Sieve Analysis Test is in good control. There were discrepant results reported, but these were attributed to the difficulty in splitting the samples uniformly.

It is suggested, for simplification, that any future correlation programs analyze the results from only one or two fine and coarse sieves. Judging by the consistent trend shown in this study, this should yield enough information to monitor the precision of the test and the uniformity of the splitting procedure.

TABLE 2

PRECISION STATEMENT TABULATION

FINE SIEVE ANALYSIS (#8 THRU #200)

SINGLE-OPERATOR PRECISION

% PASSING	VARIANCE	STANDARD DEVIATION	ACCEPTABLE RANGE OF TWO RESULTS
10	.78	.88	2.5
20	1.11	1.06	3.0
30	1.50	1.23	3.5
40	1.95	1.40	4.0
50	2.46	1.57	4.4
60	3.02	1.74	4.9
70	3.64	1.91	5.4
80	4.32	2.08	5.9
90	5.06	2.25	6.4

MULTILABORATORY PRECISION

% PASSING	VARIANCE	STANDARD DEVIATION	ACCEPTABLE RANGE OF TWO RESULTS
10	1.18	1.09	3.1
20	1.68	1.30	3.7
30	2.27	1.51	4.3
40	2.95	1.72	4.9
50	3.71	1.93	5.5
60	4.57	2.14	6.0
70	5.51	2.35	6.6
80	6.54	2.56	7.2
90	7.65	2.77	7.8

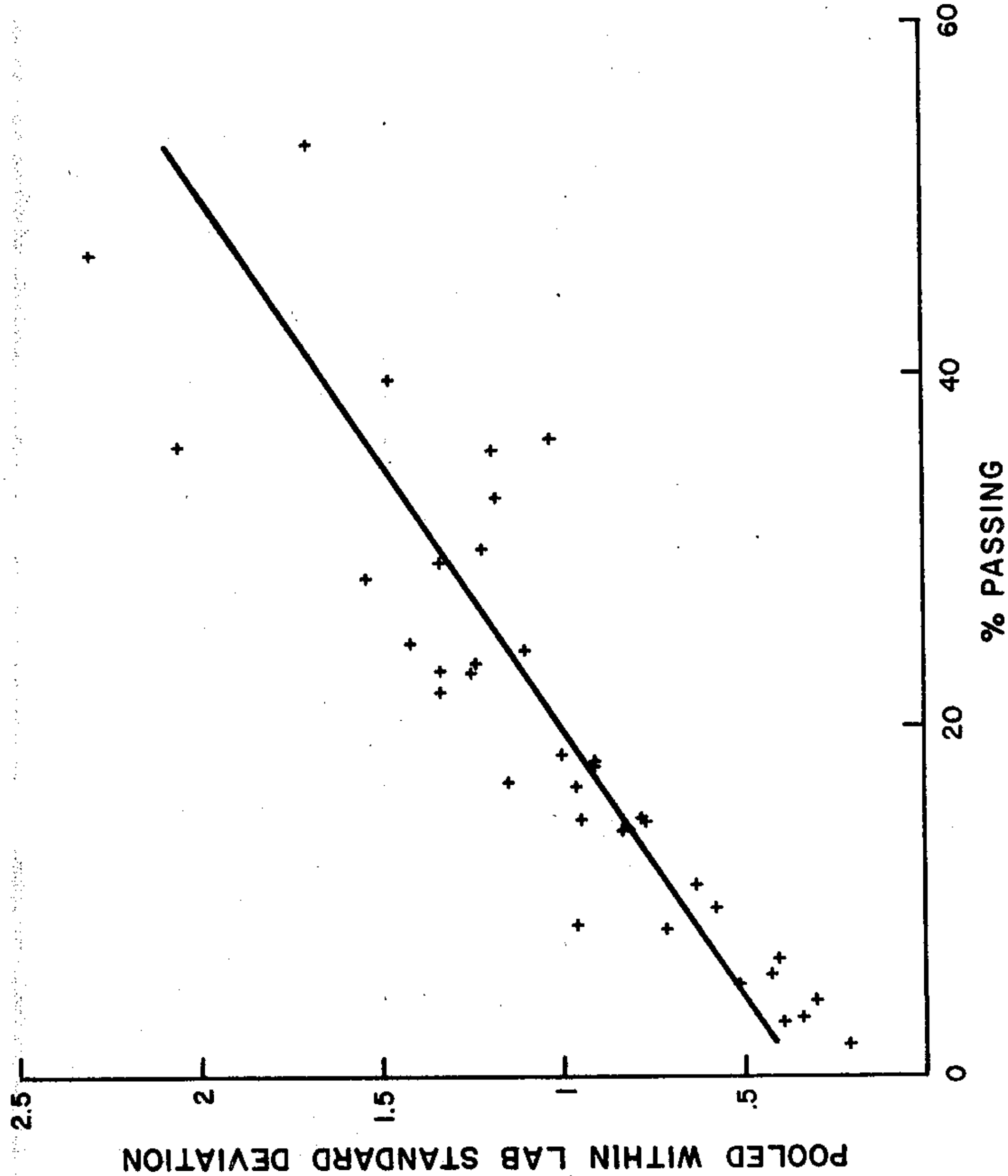

Fig.2 TEST PRECISION VS MATERIAL RANGE
COMBINED SIEVE ANALYSIS

TABLE 3

PRECISION STATEMENT TABULATION

COMBINED SIEVE ANALYSIS (#8 THRU #200)

SINGLE-OPERATOR PRECISION

% PASSING	VARIANCE	STANDARD DEVIATION	ACCEPTABLE RANGE OF TWO RESULTS
5	.24	.49	1.4
10	.41	.64	1.8
15	.64	.80	2.3
20	.91	.95	2.7
25	1.23	1.11	3.1
30	1.60	1.26	3.6
35	2.01	1.42	4.0
40	2.48	1.57	4.5
45	2.99	1.73	4.9
50	3.55	1.89	5.3

MULTILABORATORY PRECISION

% PASSING	VARIANCE	STANDARD DEVIATION	ACCEPTABLE RANGE OF TWO RESULTS
5	.32	.57	1.6
10	.56	.75	2.1
15	.86	.93	2.6
20	.22	1.11	3.1
25	1.65	1.29	3.6
30	2.15	1.47	4.1
35	2.71	1.65	4.7
40	3.34	1.83	5.2
45	4.03	2.01	5.7
50	4.78	2.19	6.2

II. % Crushed Particles Retained #4 Screen (Test Method No. Calif. 205-E)

This test evaluates, by inspection, the relative amount of crushed material contained in a sample of aggregate. The four samples tested by this method ranged from approximately 55% to 95% crushed particles. The test exhibited very large systematic errors, particularly between laboratories.

Error Distribution:

Between Laboratory	65%
Between Operator	20%
Residual Error	15%

The precision of the Crushed Particle Test was shown to be very poor, especially for materials with low crushed particle counts (see Table 4). Discrepant results roughly correlated with geographical location, with laboratories in the southern part of California getting significantly lower results than the rest of the State.

The large errors measured for this test method are most likely caused by the highly subjective nature of the test. If this test is to be continued as a contract control test, the source of these errors must be identified and minimized. A comprehensive state-wide training program would significantly improve uniformity in the application of the Crushed Particles Test.

III. L. A. Rattler (Test Method No. Calif. 211-D, 500 Rev.)

The L. A. Rattler Test is used to measure the resistance of coarse aggregate to degradation caused by impact. The range

TABLE 4

PRECISION STATEMENT TABULATION

% CRUSHED PARTICLES (RET. #4)

SINGLE-OPERATOR PRECISION

% CRUSHED	VARIANCE	STANDARD DEVIATION	ACCEPTABLE RANGE OF TWO RESULTS
55	36.96	6.08	17
60	30.74	5.54	16
65	25.10	5.01	14
70	20.02	4.47	13
75	15.52	3.94	11
80	11.59	3.40	10
85	8.23	2.87	8
90	5.45	2.33	7
95	3.24	1.80	5

MULTILABORATORY PRECISION

% CRUSHED	VARIANCE	STANDARD DEVIATION	ACCEPTABLE RANGE OF TWO RESULTS
55	263.19	16.22	46
60	218.90	14.80	42
65	178.69	13.37	38
70	142.56	11.94	34
75	110.50	10.51	30
80	82.52	9.08	26
85	58.62	7.66	22
90	38.80	6.23	18
95	23.05	4.80	14

of results studied for this test method were 13 to 18% loss. The precision measured, as shown in the following precision statement, was constant over this range.

	Variance	Standard Deviation	Acceptable Range of Two Results
Single-Operator	1.10	1.05	3.0% loss
Multilaboratory	3.53	1.88	5.3% loss

An analysis of the components of variance revealed that between laboratory error constituted 70% of the overall error. Residual error made up the remaining 30% while between operator error was negligible. Since each laboratory has only one Los Angeles Abrasion Testing Machine, it becomes obvious that equipment, not operator technique, is the most critical factor affecting the precision of the test. If further study indicates improvement in test precision is warranted, the Los Angeles abrasion machines should be checked more frequently and rigorously for conformance with specifications.

IV. Sand Equivalent (Test Method No. Calif. 217-I)

The precision of this test method was determined and reported under a separate study(10), and is included here for completeness.

Single-Operator Precision

Sand Equivalent Range	Variance	Standard Deviation	Acceptable Range of Two Results
Below 45	1.87	1.37	3.9
45-65	8.72	2.95	8.4
Above 65	4.27	2.07	5.9

Multilaboratory Precision

Sand Equivalent Range	Variance	Standard Deviation	Acceptable Range of Two Results
Below 45	2.90	1.70	4.8
45-65	14.05	3.75	10.6
Above 65	7.03	2.65	7.5

V. Cleanness Value (Test Method No. Calif. 227-E)

The cleanness test indicates the amount, fineness and character of clay-like materials and coatings present in coarse aggregate. Precision of the test was based on two samples in the 90 to 95% cleanness value range. The conclusions drawn from this limited data are preliminary, and will be augmented in the future by a continuous correlation program that has already been implemented.

Between operator error was found to be insignificant while between laboratory error constituted over 40% of the total error. This tends to indicate that there are either equipment calibration deficiencies or lack of uniform application of testing procedures from laboratory to laboratory. The actual errors are reasonably small, however, as illustrated by the precision statement:

	Variance	Standard Deviation	Acceptable Range of Two Results
Single-Operator	0.69	0.83	2.3 CV Units
Multilaboratory	1.21	1.10	3.1 CV Units

VI. Durability Index (Test Method No. Calif. 229-E)

The Durability Index is a measure of the resistance of an aggregate to produce detrimental clay-like fines when subjected to certain chemical and mechanical forms of degradation. Both Fine and Coarse Durability Methods are used. The precision of the two methods are shown in Tables 5 and 6 respectively. Test precision improves with increased durability for both methods.

Since Coarse Durability was measured for only two samples, the precision measurements shown in Table 6 should be considered preliminary. However, Fine Durability results were recorded for four samples, permitting fairly reliable measurement of the systematic errors. The breakdown of the overall Fine Durability error was as follows:

Between Laboratory	50%
Between Operator	30%
Residual Error	20%

For high range material, however, between laboratory error diminished to 20% while for low range material it increased to 60%. This indicates that the test is more sensitive at low durabilities than high durabilities to some source of error occurring between the laboratories. This error could be caused by differences in calcium chloride solutions, tap water, temperature control, or agitators. Further study identifying which of these factors is significantly affecting the precision of the test and eliminating that error should substantially improve the precision of the test.

The two sets of samples on which Fine Durability measurements were made were sent out three months apart. For the most part, the same operators ran the tests using the same equipment. However, a significant within laboratory scale-type error was measured. It appears that the most probable source of this error was a change either in laboratory temperature or calcium chloride solution concentration during the two month period.

TABLE 5

PRECISION STATEMENT TABULATION

FINE DURABILITY

SINGLE-OPERATOR PRECISION

FINE DURABILITY	VARIANCE	STANDARD DEVIATION	ACCEPTABLE RANGE OF TWO RESULTS
50	5.74	2.40	6.8
55	5.01	2.24	6.3
60	4.33	2.08	5.9
65	3.69	1.92	5.4
70	3.11	1.76	5.0
75	2.58	1.61	4.5

MULTILABORATORY PRECISION

FINE DURABILITY	VARIANCE	STANDARD DEVIATION	ACCEPTABLE RANGE OF TWO RESULTS
50	26.07	5.11	14.4
55	22.75	4.77	13.5
60	19.65	4.43	12.5
65	16.78	4.10	11.6
70	14.14	3.76	10.6
75	11.72	3.42	9.7

TABLE 6

PRECISION STATEMENT TABULATION
COARSE DURABILITY

SINGLE-OPERATOR PRECISION

COARSE DURABILITY	VARIANCE	STANDARD DEVIATION	ACCEPTABLE RANGE OF TWO RESULTS
60	12.85	3.58	10.1
65	9.42	3.07	8.7
70	6.53	2.56	7.2
75	4.16	2.04	5.8
80	2.33	1.53	4.3
85	1.02	1.01	2.9

MULTILABORATORY PRECISION

COARSE DURABILITY	VARIANCE	STANDARD DEVIATION	ACCEPTABLE RANGE OF TWO RESULTS
60	18.88	4.35	12.3
65	13.85	3.72	10.5
70	9.59	3.10	8.8
75	6.12	2.47	7.0
80	3.42	1.85	5.2
85	1.50	1.22	3.5

An experiment should be conducted to ascertain the sensitivity of the Durability Test to combinations of the two variables, temperature and calcium chloride solution concentration. These should be varied within the control limits specified by the test method. It might be advisable to obtain samples of working calcium chloride solutions from each laboratory, thus including the effect, if any, of different local tap waters.

The results of this experiment may also have implications for the Sand Equivalent and Cleanness Value Tests because of their similarities to the Durability Test.

VII. R-value (Test Method No. Calif. 301-F)

The four samples tested ranged in R-value from 30 to 85. As with many of the other tests, precision was found to vary according to the range of material tested. In the range tested, low R-value material yielded less precise test results than high R-value material.

Table 7 summarizes the single-operator and multilaboratory precision for the R-value Test.

The overall distribution of errors was as follows:

Between Laboratory	30%
Between Operator	20%
Residual Error	50%

Between laboratory error was greater than the 30% listed above for low range material. Also, significant scale-type errors of both the within and between laboratory variety were observed. The scale-type errors were possibly caused by stabilometer

TABLE 7

PRECISION STATEMENT TABULATION

R-VALUE

SINGLE-OPERATOR PRECISION

R VALUE	VARIANCE	STANDARD DEVIATION	ACCEPTABLE RANGE OF TWO RESULTS
30	38.54	6.21	18
35	32.99	5.74	16
40	27.87	5.28	15
45	23.17	4.81	14
50	18.92	4.35	12
55	15.09	3.88	11
60	11.69	3.42	10
65	8.73	2.95	8
70	6.20	2.49	7
75	4.10	2.03	6
80	2.43	1.56	4
85	1.20	1.10	3

MULTILABORATORY PRECISION

R VALUE	VARIANCE	STANDARD DEVIATION	ACCEPTABLE RANGE OF TWO RESULTS
30	76.40	8.74	25
35	65.39	8.09	23
40	55.24	7.43	21
45	45.94	6.78	19
50	37.49	6.12	17
55	29.91	5.47	15
60	23.18	4.81	14
65	17.31	4.16	12
70	12.29	3.51	10
75	8.13	2.85	8
80	4.83	2.20	6
85	2.38	1.54	4

readings since these instruments, if not properly calibrated, can give high results in one range and low results in another. Intricate sample fabrication procedures probably contributed to a large portion of the residual error measured.

The complexity of the R-value Test makes it difficult to isolate, with any degree of certainty, specific sources of general error types. However, a more comprehensive and well designed experiment could reveal much more information on the specific types of error occurring in the test method.

DESCRIPTION OF WORK

The California Department of Transportation's eleven District Materials Laboratories and its Headquarter's Laboratory were the participants in this pilot study. Sample preparation and data analysis were handled by Transportation Laboratory personnel in Sacramento. The testing program was spread out over almost two years, while the analysis phase, speeded by the use of the computer, was completed in several months.

The samples were prepared and distributed in sets of two. Samples in each set were of the same aggregate type (i.e., AC, PCC, AB or AS), but were obtained from two different sources. The test methods that were performed on each set of samples are shown in Table 8. A total of 10 individual samples were studied. The total amount of testing to be done was determined by theoretical design considerations tempered by practical constraints.

Each sample was split down into 64 sub-samples. Each of these sub-samples contained enough material to perform one series of tests. Forty-eight of these sub-samples were randomly assigned to the different laboratories. The remaining 16 sub-samples were kept as a contingency. Thus, each of the 12 participating laboratories received 4 sub-samples from each sample (see Figure 3).

TABLE 8

SUMMARY OF TESTING

Sample Nos.	Agg. Type	Dates Tested	Tests Studied	Calif. TM No.
1 & 2	PCC (Fine)	3/72 thru	Fine Sieve Analysis	202G
		5/72	Fine Durability Index	229E
3 & 4	PCC (Coarse)	3/72 thru	Coarse Sieve Analysis	202G
		5/72	L. A. Rattler	211D
			Cleanness Value	227E
5 & 6	AB	6/72 thru	Sieve Analysis	202G
		10/72	Durability Index	229E
			% Crushed Particles	205E
			R-value	301F
7 & 8	AC	7/73 thru	Sieve Analysis	202G
		11/73	L. A. Rattler	229E
			% Crushed Particles	205E
9 & 0	AS	4/73 thru	Sieve Analysis	202G
		6/73	R-value	301F

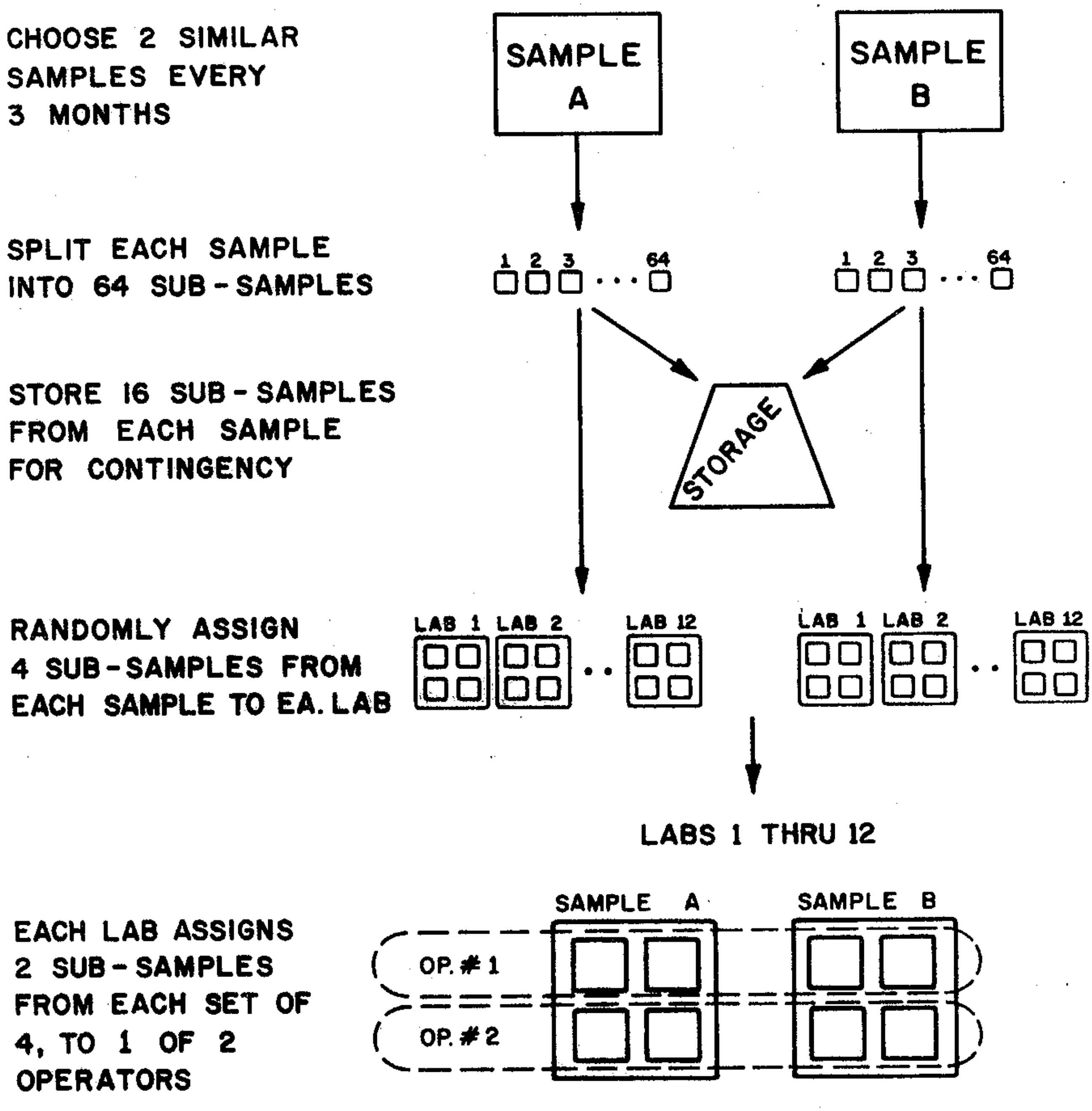

Fig.3 SAMPLE DISTRIBUTION

At the beginning of each three-month interval the laboratories received their two sets of four sub-samples each. They then chose two operators and set aside one set of equipment. On the day or days that the tests were to be made, each operator was given two sub-samples from each sample. The operators ran the indicated tests following their usual procedure. The operators used the same set of equipment for the four sub-samples tested.

ANALYSIS

Only brief mention of the analytical techniques employed in this study will be made here. A more complete discussion can be found in reference [2].

Precision statements were determined by using a three factorial analysis of variance and isolating the components of variance according to expected mean square equations. These same components were used to estimate the relative distribution of the general error types: between operator, between laboratory and residual.

The relationship between test precision and material range was investigated for each of the test methods studied. This was done by linearly regressing the pooled within lab standard deviations against the overall sample averages. If no significant precision-material range relationship was indicated, an analysis of variance was carried out on the data in its original form with components of variance being isolated and then recombined to form the desired types of precision statements. However, if a significant relationship was shown the data was then transformed according to equation (1) and an analysis of variance performed on this transformed data. The resulting components of variance were then retransformed according to equation (2) which is derived from the rules for propagation of error [6]. Because the precision estimates yielded by equation (2) are a function of material range (y), tabular formats were used to report precision in these cases

(1) $z = K \ln(A+By)-G$

(2) $\sigma_y^2 = \frac{1}{K^2}\left[\frac{A}{B}+y\right]^2 \sigma_z^2$

A = Intercept of precision-material range regression line.

B = Slope of same.

K & G = Arbitrary constants chose for convenience.

y = Test result.

z = Transformed test result.

σ^2 = Variance.

Scale-type errors were derived from John Mandel's linear model analysis [6 & 7]. Variations in the distribution of errors from different sources as a function of material range were also studied using this method. Laboratory performance was monitored by using scatter diagrams and ranking summaries. See Appendices B and C for a more detailed discussion of these techniques.

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APPENDIX A

SUMMARY OF RESULTS

The following pages summarize the results by laboratory and sample for each test method studied. At the top of each page the results of a regression analysis run between pooled within lab standard deviation and sample average are shown. The slope of the regression equation should be equal or nearly equal to zero in order to satisfy the assumption of cell variance homogeneity. If the slope differs significantly from zero, the index of determination is greater than 0.5 and the F-Ratio for regression greater than 4, a logarithmic transformation of the form $Z = K \text{Log}_{10}(A+By)+C$ (A = y-intercept, B = slope, K and C are constants chosen for convenience) was used in the analysis.

The remainder of the page is devoted to a summary of results. For each laboratory-sample combination the mean and standard deviation of the four test results (two replicate tests by two operators) are listed. At the bottom of the summary the overall average and pooled standard deviation for each sample is given.

ANALYSIS OF INTERLABORATORY RESULTS

% CRUSHED PARTICLES (RET. #4)

SUMMARY OF RESULTS:

REGRESSION EQUATION-STANDARD DEVIATION VS. TEST PARAMETER:
Y = 18.449 + (-.165)X   INDEX OF DETER. = .714   F-RATIO = 4.98

LABORATORY	SAMPLE 5	SAMPLE 6	SAMPLE 7	SAMPLE 8
A	61.37	44.35	73.30	91.08
	14.06	12.44	4.90	2.21
B	93.55	64.13	86.43	96.30
	.17	7.03	1.32	.70
C	86.45	62.23	75.62	94.18
	3.62	9.17	5.99	1.48
D	82.33	57.75	88.75	95.00
	13.04	16.65	1.50	.82
E	90.85	60.32	81.10	93.98
	2.37	3.59	2.54	1.39
F	74.00	43.75	81.15	93.83
	3.92	4.99	4.25	.91
G	95.00	74.00	86.75	94.00
	.82	1.41	2.36	2.45
H	95.00	69.75	90.75	96.75
	4.24	8.73	6.70	2.63
I	89.50	35.25	79.58	92.98
	2.08	2.50	1.45	1.17
J	88.50	62.00	74.75	88.00
	1.73	9.42	5.62	2.45
K	99.50	87.00	95.05	98.18
	.58	2.83	2.03	1.11
L	78.50	59.25	75.43	91.65
	8.23	7.09	4.08	2.66
AVERAGE	86.21	59.98	82.39	93.83*
	6.43	8.34	4.01	1.82**

* - SAMPLE MEAN
**- STANDARD DEVIATION

ANALYSIS OF INTERLABORATORY RESULTS

LA RATTLER (500 REV)

SUMMARY OF RESULTS:

REGRESSION EQUATION-STANDARD DEVIATION VS. TEST PARAMETER:
Y = .791 + (-.008)X   INDEX OF DETER. = .015   F-RATIO = .03

LABORATORY	SAMPLE 3	4	7	8
A	14.25 1.26	18.25 .50	17.80 .31	15.00 .77
B	11.18 .71	16.33 .41	16.93 .33	13.65 .13
C	14.97 .61	19.95 .37	18.28 .56	16.60 .43
D	11.22 .79	16.55 .57	16.33 .46	13.08 .10
E	14.12 .25	19.10 .78	18.55 .29	16.05 .76
F	10.90 .35	13.65 1.08	14.50 .58	12.00 .00
G	11.00 .00	16.00 .00	16.07 .41	12.62 .22
H	15.52 1.20	20.18 .56	18.50 1.73	16.00 .82
I	12.75 .50	17.00 .00	17.43 .99	14.98 .54
J	13.25 1.26	17.25 .50	17.25 .50	13.75 .50
K	13.75 .96	17.50 .58	17.50 1.29	15.25 .50
L	14.65 .30	20.05 .74	19.10 .26	16.45 .19
AVERAGE	13.13 .79	17.65 .58	17.35 .78	14.62* .49**

* - SAMPLE MEAN
**- STANDARD DEVIATION

COARSE DURABILITY

SUMMARY OF RESULTS:

REGRESSION EQUATION-STANDARD DEVIATION VS. TEST PARAMETER:
Y = 11.093 + (-.117)X   INDEX OF DETER. = 1.000   F-RATIO = .00

LABORATORY	SAMPLE 5	SAMPLE 6
A	60.00	80.25
	2.45	2.87
B	63.50	83.50
	3.32	1.73
C	63.25	82.75
	5.32	1.50
D	60.75	80.00
	5.56	1.63
E	65.75	82.25
	2.06	2.06
F	62.75	79.00
	.50	1.15
G	62.50	80.00
	3.11	1.63
H	63.00	85.00
	4.83	.00
I	64.00	85.50
	1.83	1.00
J	66.00	85.00
	2.45	.00
K	67.25	81.00
	2.22	1.15
L	64.25	81.50
	5.91	1.00
AVERAGE	63.58	82.15*
	3.68	1.52**

* - SAMPLE MEAN
**- STANDARD DEVIATION

FINE DURABILITY

SUMMARY OF RESULTS:

REGRESSION EQUATION-STANDARD DEVIATION VS. TEST PARAMETER:
Y = 5.287 + (-.042)X   INDEX OF DETER. = .996   F-RATIO =567.66

LABORATORY	SAMPLE 1	SAMPLE 2	SAMPLE 5	SAMPLE 6
A	74.75	65.50	53.75	68.00
	2.63	3.32	5.85	3.37
B	73.50	62.75	53.75	65.00
	.58	.50	4.79	1.63
C	72.50	64.00	52.30	60.98
	.58	.82	1.09	1.58
D	75.55	67.90	59.25	69.75
	.66	2.80	2.99	.50
E	74.00	61.25	52.50	60.00
	4.76	2.75	.58	.00
F	69.25	61.50	56.00	62.25
	2.22	1.29	.82	.50
G	75.00	68.25	61.00	72.50
	.82	3.86	2.83	2.08
H	72.25	62.00	47.50	60.25
	.50	1.41	3.32	.96
I	74.50	64.25	62.50	75.00
	1.73	3.30	1.73	5.66
J	73.50	64.25	60.00	65.75
	1.29	1.71	1.41	2.06
K	73.25	63.00	47.75	61.25
	3.86	4.24	1.71	3.40
L	77.25	66.25	57.25	69.75
	1.50	2.22	3.30	2.36
AVERAGE	73.77	64.24	55.30	65.87*
	2.21	2.62	2.97	2.51**

* - SAMPLE MEAN
**- STANDARD DEVIATION

R-VALUE

SUMMARY OF RESULTS:

REGRESSION EQUATION-STANDARD DEVIATION VS. TEST PARAMETER:
Y = 9.872 + (-.102)X   INDEX OF DETER. = .976   F-RATIO = 82.42

LABORATORY	SAMPLE 5	SAMPLE 6	SAMPLE 9	SAMPLE 0
A	81.25	83.00	21.25	28.75
	2.06	.82	3.52	1.50
B	82.50	83.50	45.00	61.25
	.58	1.29	6.48	5.19
C	83.50	83.25	35.62	53.62
	1.29	.96	3.28	4.52
D	82.00	81.75	23.75	54.25
	1.41	2.75	4.79	6.24
E	81.25	82.25	32.00	49.00
	.50	1.50	1.63	4.24
F	79.00	81.25	39.75	50.25
	1.41	.96	11.09	2.75
G	79.75	82.00	43.00	49.25
	.50	1.83	10.10	5.25
H	82.00	82.75	24.75	34.50
	1.15	1.71	2.22	4.04
I	84.00	85.00	37.75	56.00
	.82	1.41	4.11	4.24
J	82.50	83.25	26.50	45.25
	2.08	1.26	2.38	.50
K	81.00	82.75	44.50	55.00
	1.41	.96	1.29	6.27
L	80.00	82.50	30.00	38.75
	.00	1.29	9.83	11.95
AVERAGE	81.56	82.77	33.66	47.99*
	1.26	1.48	6.07	5.47**

* - SAMPLE MEAN
**- STANDARD DEVIATION

ANALYSIS OF INTERLABORATORY RESULTS

COARSE SIEVE ANALYSIS (3/4")

SUMMARY OF RESULTS:

REGRESSION EQUATION-STANDARD DEVIATION VS. TEST PARAMETER:
Y = 7.254 + (-.067)X   INDEX OF DETER. = .730   F-RATIO = 16.19

LABORATORY	SAMPLE 3	4	5	6	7	8	9	0
A	84.00 1.15	76.75 2.87	92.15 1.58	96.98 .24	95.53 .69	99.00 .28	96.52 .70	95.85 1.45
B	83.95 1.16	77.05 1.64	90.88 1.66	96.20 .32	95.00 .50	98.62 .05	97.98 .45	95.00 .53
C	83.70 1.06	77.45 1.33	91.38 .90	95.98 .69	95.90 .42	98.75 .25	96.95 .76	95.12 .56
D	86.30 1.32	77.90 .80	91.15 1.59	97.20 .41	97.03 .49	99.30 .08	96.87 1.10	95.73 .79
E	84.13 1.17	77.08 1.38	91.95 1.45	96.65 .53	95.48 .24	98.98 .15	96.43 .43	95.25 .24
F	87.00 3.16	79.25 2.22	92.90 1.06	97.73 .33	96.27 .33	99.50 .16	97.58 1.61	96.18 .79
G	84.00 1.83	78.75 .50	91.05 1.68	96.78 .15	96.25 .44	99.15 .31	96.88 .88	95.48 .61
H	83.68 1.69	74.98 3.06	90.50 1.88	96.73 .70	95.33 .43	99.18 .24	97.85 .64	96.45 .72
I	84.00 1.63	78.25 .96	92.33 .43	96.83 .57	95.48 .75	99.25 .42	97.10 .52	94.70 1.06
J	82.00 2.00	75.75 1.50	89.50 .54	95.83 .79	94.75 .79	98.30 .14	97.35 .82	94.95 .61
K	83.50 1.91	75.75 .96	90.33 1.59	95.70 1.82	95.20 1.19	98.77 .24	97.73 .43	95.65 1.20
L	85.53 2.06	77.73 1.72	93.85 3.64	96.53 .62	95.27 .79	98.55 .13	97.50 .91	95.87 .10
AVERAGE	84.31 1.77	77.22 1.75	91.50 1.69	96.59 .73	95.62 .64	98.95 .23	97.23 .84	95.52* .81**

* - SAMPLE MEAN
**- STANDARD DEVIATION

COARSE SIEVE ANALYSIS (1/2")

SUMMARY OF RESULTS:

REGRESSION EQUATION-STANDARD DEVIATION VS. TEST PARAMETER:
Y = 1.487 + (.002)X INDEX OF DETER. = .012 F-RATIO = .05

LABORATORY	SAMPLE 3	4	5	6	7	8
A	47.00 1.41	40.25 2.87	75.40 1.56	80.23 1.70	78.15 1.35	81.98 1.27
B	46.55 .65	41.37 1.24	74.75 1.55	79.35 .58	76.43 .57	82.80 1.09
C	46.20 1.15	40.88 1.83	74.68 1.30	78.65 .35	78.43 .53	81.93 .95
D	51.85 1.36	44.93 1.12	75.52 1.72	81.95 1.81	82.50 1.11	85.15 1.17
E	47.85 1.94	43.32 1.75	77.05 1.86	81.23 .51	78.08 1.65	83.08 .95
F	51.75 2.22	46.75 1.71	76.45 1.89	83.33 1.53	81.78 1.31	84.37 1.07
G	47.75 .50	42.00 .00	74.75 2.07	79.50 1.28	80.80 .45	83.98 1.74
H	48.15 1.50	41.48 1.99	74.85 1.86	80.60 1.60	78.90 .42	83.58 1.14
I	47.00 2.16	42.50 1.29	75.98 1.18	80.68 1.20	78.40 1.15	83.00 1.40
J	45.75 1.71	40.25 .96	73.93 .71	79.25 1.67	77.25 1.62	81.70 1.08
K	44.50 1.29	38.00 1.41	73.10 1.75	76.25 1.64	75.85 2.52	76.37 5.59
L	47.80 1.85	41.75 .54	77.93 3.93	80.48 .87	77.73 1.11	82.02 .59
AVERAGE	47.68 1.57	41.96 1.56	75.36 1.93	80.12 1.33	78.69 1.29	82.50* 1.96**

* - SAMPLE MEAN
**- STANDARD DEVIATION

COARSE SIEVE ANALYSIS (3/8")

SUMMARY OF RESULTS:

REGRESSION EQUATION-STANDARD DEVIATION VS. TEST PARAMETER:
Y = .916 + (.010)X INDEX OF DETER. = .374 F-RATIO = 3.59

LABORATORY	SAMPLE 3	4	5	6	7	8	9	0
A	27.75	15.75	70.35	72.03	65.60	69.10	84.25	79.70
	1.50	3.20	1.64	5.19	1.61	1.28	1.12	3.04
B	26.78	15.95	69.75	68.18	64.40	68.90	90.05	78.85
	.45	.66	1.41	.62	.55	1.36	1.56	.62
C	26.87	16.53	69.73	67.37	65.35	68.25	87.75	78.93
	.62	.94	1.45	.57	.24	1.45	1.32	1.05
D	29.15	17.98	70.27	70.00	67.50	71.18	86.33	79.95
	.95	.85	1.65	1.43	1.08	.97	2.41	1.13
E	27.60	17.62	71.02	69.60	65.03	69.27	86.18	77.90
	1.04	.76	2.21	1.10	1.70	1.07	.76	1.76
F	27.75	17.50	69.65	70.80	66.27	69.75	87.88	79.70
	.96	.58	1.95	2.06	1.59	.79	2.08	.22
G	27.75	16.50	69.68	67.93	67.03	70.68	85.63	80.12
	.50	.58	2.14	1.55	.15	1.72	.99	2.69
H	27.55	16.93	69.93	69.68	66.20	70.87	90.35	81.12
	.82	1.20	1.81	2.33	.61	1.40	1.42	1.27
I	28.25	16.75	70.67	69.62	64.98	69.40	86.62	77.10
	.50	.96	.99	1.19	.81	1.85	1.31	1.23
J	25.75	14.25	69.37	67.68	64.15	67.27	86.95	78.10
	.96	.96	.59	1.98	1.37	1.50	1.30	.95
K	26.75	14.50	69.03	66.08	65.33	66.87	86.98	79.43
	.96	1.29	1.55	1.72	1.83	1.69	2.25	1.89
L	27.23	16.40	72.75	69.23	65.30	68.55	86.67	79.83
	1.11	.22	3.84	1.44	1.51	.76	1.67	.90
AVERAGE	27.43	16.39	70.18	69.01	65.59	69.18	87.14	79.23*
	.91	1.24	1.93	2.11	1.23	1.37	1.59	1.60**

* - SAMPLE MEAN
**- STANDARD DEVIATION

COARSE SIEVE ANALYSIS (#4)

SUMMARY OF RESULTS:

REGRESSION EQUATION—STANDARD DEVIATION VS. TEST PARAMETER:
Y = .077 + (.029)X INDEX OF DETER. = .817 F-RATIO = 26.86

LABORATORY	SAMPLE 3	4	5	6	7	8	9	0
A	3.50 .58	1.00 .00	42.12 1.00	46.78 1.42	43.78 .97	47.18 .67	61.55 .58	58.37 2.57
B	2.65 .06	.55 .10	42.55 1.92	46.20 .69	43.82 .74	47.95 .79	71.40 1.86	59.83 .15
C	2.62 .10	.48 .05	42.93 .83	45.65 .90	43.70 .29	47.48 1.04	63.30 4.11	58.37 1.27
D	3.50 .47	1.10 .38	43.70 1.46	47.53 1.23	44.05 .84	47.40 1.04	67.73 3.32	59.83 1.28
E	2.98 .17	.80 .27	44.18 1.36	45.23 1.44	43.58 .79	47.40 .86	64.85 1.33	57.35 3.34
F	3.00 .00	1.00 .00	43.05 1.30	47.65 1.49	44.88 1.10	47.55 .99	68.38 2.40	61.07 .73
G	3.00 .00	1.00 .00	42.90 1.45	46.90 1.77	44.48 .57	49.00 1.28	63.63 1.13	60.95 5.39
H	2.80 .27	.60 .00	43.85 .98	47.08 1.41	44.28 .53	47.77 .96	73.55 1.47	61.23 1.10
I	3.00 .00	.50 .58	43.73 .83	46.83 .90	43.68 .44	47.85 1.36	67.43 2.01	60.18 .69
J	2.50 .58	1.00 .00	42.73 .63	46.32 1.47	43.43 1.31	46.88 1.56	68.08 2.30	61.05 .70
K	3.00 .00	1.00 .00	39.93 2.01	44.18 1.15	44.05 1.13	47.82 1.07	67.02 1.96	62.25 3.60
L	2.80 .16	.85 .06	45.98 2.45	46.90 1.05	44.10 .99	47.12 .35	68.05 1.44	62.03 .69
AVERAGE	2.95 .29	.82 .22	43.14 1.45	46.44 1.28	43.98 .86	47.62 1.04	67.08 2.20	60.21* 2.35**

* - SAMPLE MEAN
**- STANDARD DEVIATION

ANALYSIS OF INTERLABORATORY RESULTS

COMBINED SIEVE ANALYSIS (#8)

SUMMARY OF RESULTS:

REGRESSION EQUATION—STANDARD DEVIATION VS. TEST PARAMETER:
Y = .033 + (.037)X   INDEX OF DETER. = .489   F-RATIO = 3.83

LABORATORY	SAMPLE 5	6	7	8	9	0
A	28.23	33.60	36.68	35.93	49.28	46.05
	1.22	.96	.92	.94	.76	2.45
B	29.37	32.77	36.85	35.08	56.30	47.08
	1.52	.98	.83	1.01	1.90	.92
C	29.37	33.35	36.28	36.78	51.43	46.50
	.59	.53	.22	.86	3.23	1.24
D	29.58	33.90	36.05	35.82	53.13	46.28
	.85	1.80	.70	1.00	2.06	.67
E	28.50	31.03	34.48	34.40	50.35	43.85
	.96	1.13	.49	.42	.99	2.38
F	28.50	32.73	35.43	35.00	51.98	47.57
	1.51	2.41	1.58	.96	2.39	2.97
G	29.85	33.58	36.95	35.28	50.63	47.75
	1.63	.53	1.64	1.14	.57	4.85
H	29.50	31.90	36.35	35.23	58.28	46.65
	.63	1.36	1.52	1.31	1.40	1.02
I	30.35	32.93	34.45	35.68	52.73	46.33
	.60	.55	.96	1.88	1.03	.70
J	29.30	33.15	35.95	34.37	52.15	46.60
	1.27	.71	.61	1.02	.70	.48
K	26.80	31.15	38.60	37.95	55.55	49.20
	2.16	1.04	.91	2.12	2.19	3.83
L	30.73	34.13	36.52	35.62	53.45	47.45
	1.90	.46	.90	.30	.72	.51
AVERAGE	29.17	32.85	36.21	35.59	52.94	46.78*
	1.34	1.18	1.03	1.19	1.70	2.30**

* – SAMPLE MEAN
**- STANDARD DEVIATION

COMBINED SIEVE ANALYSIS (#16)

SUMMARY OF RESULTS:

REGRESSION EQUATION—STANDARD DEVIATION VS. TEST PARAMETER:
Y = .610 + (.029)X   INDEX OF DETER. = .438   F-RATIO = 3.12

LABORATORY	SAMPLE 5	6	7	8	9	0
A	20.73	24.28	25.53	25.32	37.20	35.40
	.99	.52	.72	.86	.79	2.17
B	21.78	23.08	25.12	23.33	42.37	36.28
	1.32	.46	1.20	1.03	2.05	1.47
C	21.78	24.20	24.75	25.45	37.15	35.37
	.74	.65	.41	.71	1.80	1.42
D	22.85	23.55	24.03	24.18	39.20	34.82
	2.66	1.72	.59	.78	1.86	.60
E	21.53	22.55	23.33	24.55	38.03	34.05
	.88	.89	.43	.47	.43	1.83
F	21.58	23.18	23.28	24.48	39.28	37.12
	1.37	2.39	1.35	.87	1.59	3.21
G	22.12	24.20	24.72	23.62	37.28	36.07
	1.33	.68	.52	1.16	1.07	3.30
H	22.05	22.33	24.22	24.10	44.98	35.30
	.29	1.48	1.35	1.54	1.62	1.24
I	22.73	23.33	21.87	24.78	38.98	35.10
	.56	.43	2.45	2.40	.78	1.21
J	21.65	23.53	21.80	22.72	38.68	35.53
	1.07	.49	.70	2.11	.29	.56
K	20.68	23.38	27.53	28.00	42.33	38.80
	1.59	2.18	.81	2.49	2.60	3.65
L	23.05	24.35	24.35	24.72	39.75	35.98
	1.60	.47	.94	.29	.88	.50
AVERAGE	21.88	23.49	24.21	24.60	39.60	35.82*
	1.34	1.24	1.10	1.42	1.48	2.06**

* - SAMPLE MEAN
**- STANDARD DEVIATION

COMBINED SIEVE ANALYSIS (#30)

SUMMARY OF RESULTS:

REGRESSION EQUATION-STANDARD DEVIATION VS. TEST PARAMETER:
Y = .531 + (.029) X   INDEX OF DETER. = .630   F-RATIO = 6.82

LABORATORY	SAMPLE 5	6	7	8	9	0
A	16.68 .88	17.12 .36	15.38 .51	17.05 .48	27.75 .68	27.75 1.96
B	17.70 1.10	15.93 .67	15.35 1.30	15.60 .82	32.10 1.91	29.03 1.26
C	17.73 .72	17.60 .71	15.08 .62	17.33 .73	28.83 1.30	27.90 .61
D	17.40 .82	16.33 1.38	14.05 .33	16.12 .50	29.40 1.45	27.50 .41
E	17.45 .58	15.78 .62	13.78 .36	16.70 .45	28.73 .31	27.00 1.47
F	17.60 1.21	16.18 2.03	13.40 1.06	16.37 .67	29.75 1.05	29.20 1.71
G	17.75 .97	17.28 .78	14.72 .19	16.12 .52	27.83 .88	28.15 2.58
H	17.93 .19	15.80 1.23	14.28 .99	16.28 1.23	35.18 1.77	28.05 1.08
I	18.58 .46	16.53 .84	12.30 2.07	16.83 2.33	29.60 .59	27.93 1.02
J	17.45 .78	16.45 .42	14.95 .79	15.95 1.26	28.90 .34	28.05 .52
K	16.87 1.23	15.83 .46	17.10 .87	19.55 2.18	31.55 1.97	30.68 2.79
L	18.75 1.26	17.32 .50	15.15 .62	16.98 .25	29.90 .72	28.38 .66
AVERAGE	17.66 .91	16.51 .96	14.63 .95	16.74 1.15	29.96 1.22	28.30* 1.54**

* - SAMPLE MEAN
**- STANDARD DEVIATION

ANALYSIS OF INTERLABORATORY RESULTS

COMBINED SIEVE ANALYSIS (#50)

SUMMARY OF RESULTS:

REGRESSION EQUATION-STANDARD DEVIATION VS. TEST PARAMETER:
Y = .384 + (.038)X   INDEX OF DETER. = .730   F-RATIO = 10.80

LABORATORY	SAMPLE 5	6	7	8	9	0
A	13.78	10.05	10.28	8.65	21.20	22.40
	.67	.24	2.25	.21	.45	1.59
B	14.78	9.93	9.20	7.90	24.85	23.55
	1.05	.10	.91	.50	1.61	1.08
C	14.68	10.25	8.87	8.53	22.15	22.68
	.55	.52	.64	.55	.96	.80
D	14.30	9.18	8.08	7.87	22.50	22.12
	.78	.87	.40	.26	1.07	.33
E	14.35	8.87	8.05	8.20	22.18	21.95
	.50	.26	.26	.36	.13	1.26
F	14.62	9.25	7.85	7.70	22.93	23.60
	1.06	1.29	.59	.77	.67	1.09
G	14.62	9.83	8.35	8.30	20.55	22.55
	.83	.53	.25	.36	.91	2.33
H	14.75	9.03	8.25	7.95	27.63	22.70
	.25	.75	.62	.66	1.93	.78
I	15.40	9.75	7.00	8.43	22.68	22.55
	.39	.25	1.49	1.24	.52	.77
J	14.45	9.37	8.85	8.08	22.25	22.53
	.44	.29	.89	.71	.39	.28
K	13.78	8.90	10.23	9.87	25.10	25.88
	1.01	.22	.78	1.39	3.28	2.12
L	15.63	10.20	9.03	8.47	23.10	22.93
	1.05	.29	.44	.28	.68	.57
AVERAGE	14.59	9.55	8.67	8.33	23.09	22.95*
	.77	.57	.96	.71	1.34	1.25**

* - SAMPLE MEAN
**- STANDARD DEVIATION

COMBINED SIEVE ANALYSIS (#100)

SUMMARY OF RESULTS:

REGRESSION EQUATION-STANDARD DEVIATION VS. TEST PARAMETER:
Y = .226 + (.040)X   INDEX OF DETER. = .965   F-RATIO =111.28

LABORATORY	SAMPLE 5	6	7	8	9	0
A	10.38	5.93	5.55	3.50	16.15	18.00
	.50	.10	.30	.08	.25	1.29
B	11.13	5.83	5.53	3.28	19.33	18.90
	.68	.15	.56	.31	1.13	.77
C	10.80	6.13	5.23	3.33	17.00	17.90
	.43	.38	.50	.39	.82	.55
D	10.65	5.60	4.73	3.00	17.35	17.58
	.71	.91	.30	.24	.99	.34
E	10.60	5.43	4.58	3.30	17.12	17.68
	.34	.28	.15	.20	.17	1.06
F	11.33	5.80	4.93	3.48	18.15	19.48
	.86	.83	.32	.22	.52	1.02
G	11.05	6.03	5.28	3.45	16.08	18.18
	.71	.28	.38	.06	.15	1.89
H	11.17	5.68	4.98	3.30	22.08	18.48
	.25	.46	.59	.45	2.13	.76
I	11.73	5.90	4.02	3.40	17.85	18.25
	.33	.14	.71	.51	.51	.44
J	10.75	5.50	5.50	3.35	17.18	17.98
	.45	.20	.96	.33	.36	.29
K	9.93	5.40	6.03	3.88	18.15	19.50
	.90	.18	.54	.59	1.01	1.52
L	11.70	6.25	5.43	3.35	17.78	18.18
	.87	.10	.33	.17	.85	.65
AVERAGE	10.93	5.79	5.15	3.38	17.85	18.34*
	.63	.42	.51	.34	.91	1.00**

* - SAMPLE MEAN
**- STANDARD DEVIATION

COMBINED SIEVE ANALYSIS (#200)

SUMMARY OF RESULTS:

REGRESSION EQUATION—STANDARD DEVIATION VS. TEST PARAMETER:
Y = .154 + (.045) X   INDEX OF DETER. = .942   F-RATIO = 64.70

LABORATORY	SAMPLE 5	6	7	8	9	0
A	6.18	4.25	3.23	1.78	13.48	14.90
	.35	.17	.15	.10	.49	.78
B	6.08	4.28	3.05	1.65	14.90	14.85
	.34	.15	.31	.19	.88	.49
C	6.60	4.60	3.08	1.68	13.25	14.37
	.27	.33	.46	.32	.65	.33
D	6.35	4.12	2.65	1.40	13.35	13.87
	.62	.62	.26	.18	.87	.33
E	6.58	4.00	2.60	1.70	13.30	14.13
	.17	.24	.08	.28	.08	.89
F	7.03	4.27	2.93	1.75	14.08	15.53
	.59	.49	.13	.17	.49	.72
G	6.68	4.45	3.08	1.95	12.18	14.65
	.38	.19	.05	.06	.42	1.60
H	6.93	4.25	2.93	1.70	17.55	14.85
	.17	.31	.46	.33	2.01	.52
I	7.10	4.30	2.35	1.75	13.92	14.60
	.34	.08	.30	.17	.43	.34
J	6.40	4.08	3.85	1.93	13.45	14.33
	.20	.17	.97	.13	.42	.22
K	6.35	4.20	3.70	2.12	14.50	15.98
	.45	.18	.35	.29	.80	1.20
L	7.52	4.75	3.30	1.78	13.93	14.58
	.56	.10	.18	.13	.83	.64
AVERAGE	6.65	4.30	3.06	1.76	13.99	14.72*
	.40	.30	.39	.21	.83	.78**

* - SAMPLE MEAN
**- STANDARD DEVIATION

APPENDIX B

SCATTER DIAGRAMS

The scatter diagram is a convenient and informative way of displaying interlaboratory correlation results. To construct the diagram, the average of an operator's two results on one sample are assigned as his x-coordinate. His y-coordinate is assigned in the same way, but is based on the average of his results for a sample from a second source of similar material. Figure B-1 illustrates how results for two operators from separate laboratories would appear. A set of axes covering the range of all results for each sample are drawn such that they intersect at the point representing the mean of the results for each of the two samples. These axes divide the "scatter" diagram into four separate quadrants as labeled in Figure B-2.

Because of random errors in sample preparation and testing, the points will tend to form a circular cluster about the intersection of the axes as shown in Figure B-2. The radius of this cluster is an indication of the precision of the test. If, however, a bias or consistent error in the results is present and measureable then quadrants I and III will contain significantly more points than quadrants II and IV (see Figure B-3). This follows from a basic principle: operators obtaining consistently high or low results on one sample will obtain high or low results, respectively, on other similar samples.

Following are the actual scatter diagrams for this study. Since 12 laboratories participated in the study, 24 separate data points represented by 12 letters of the alphabet are plotted on each scatter diagram. Since there are two operators participating from each laboratory, each letter appears twice. The scale,

S C A T T E R   D I A G R A M

EXAMPLE

SCALE: 1" = 1 UNIT

		SAMPLE X	SAMPLE Y
Lab.A Oper.#1	Results	55 56	74 74
	Average	55.5	74
Lab.B Oper.#2	Results	52 53	71 71
	Average	52.5	71

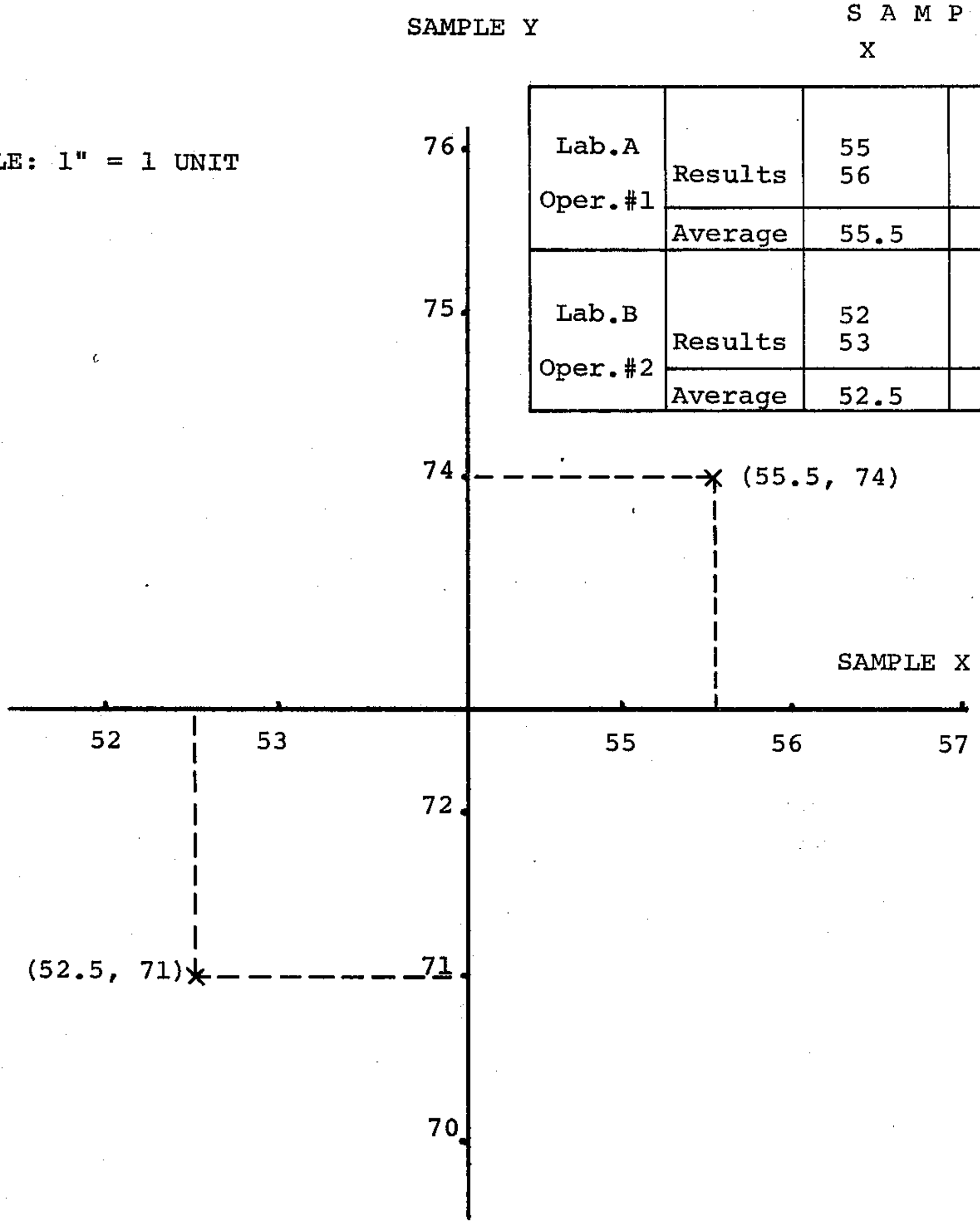


FIGURE B-1. CONSTRUCTION OF SCATTER DIAGRAM

S C A T T E R   D I A G R A M

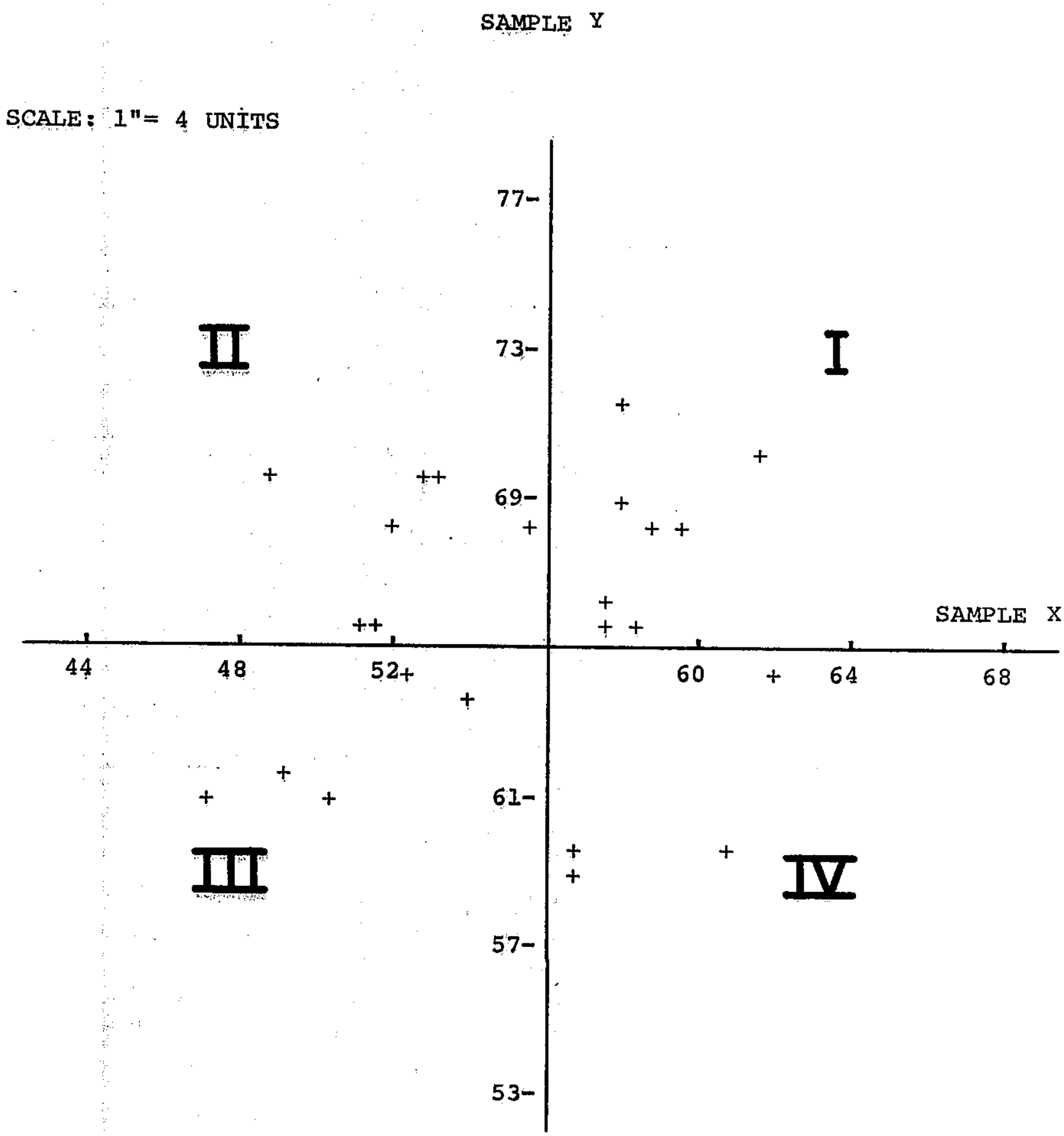


FIGURE B-2 QUADRANTS AND TYPICAL SCATTER FROM TEST EXHIBITING RANDOM ERROR ONLY

SCATTER DIAGRAM

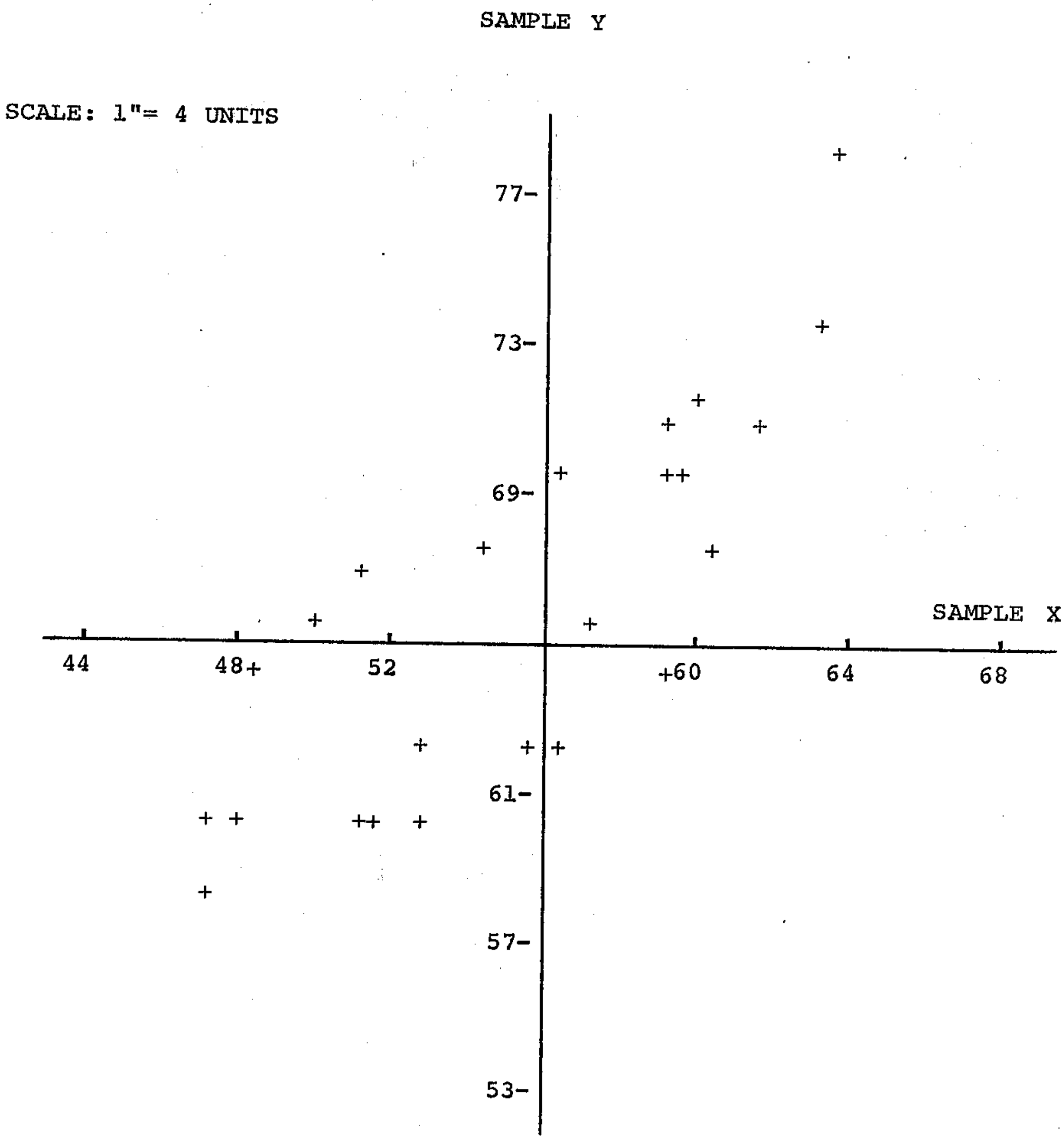


FIGURE B-3 TYPICAL SCATTER FROM TEST EXHIBITING SIGNIFICANT SYSTEMATIC ERROR automatically set by the computer, is given in the upper left corner of the diagram. The axes are labeled for the sample they represent.

The main advantage of the scatter diagram is its simplicity. Many qualitative conclusions can be drawn from the diagram if one simple principle is remembered: Bias, if any exists or has been measured, will be consistent for both samples. But the scatter diagram is only one of several powerful analytical tools available. Analysis of variance and ranking analysis are some other important techniques. Used together these tools will measure the precision of a test, quantify general sources of error (such as operator, laboratory or equipment), and evaluate the performance of laboratories or even specific operators. If improvement of test precision is warranted, these analyses can indicate the general area where the improvement should be made.

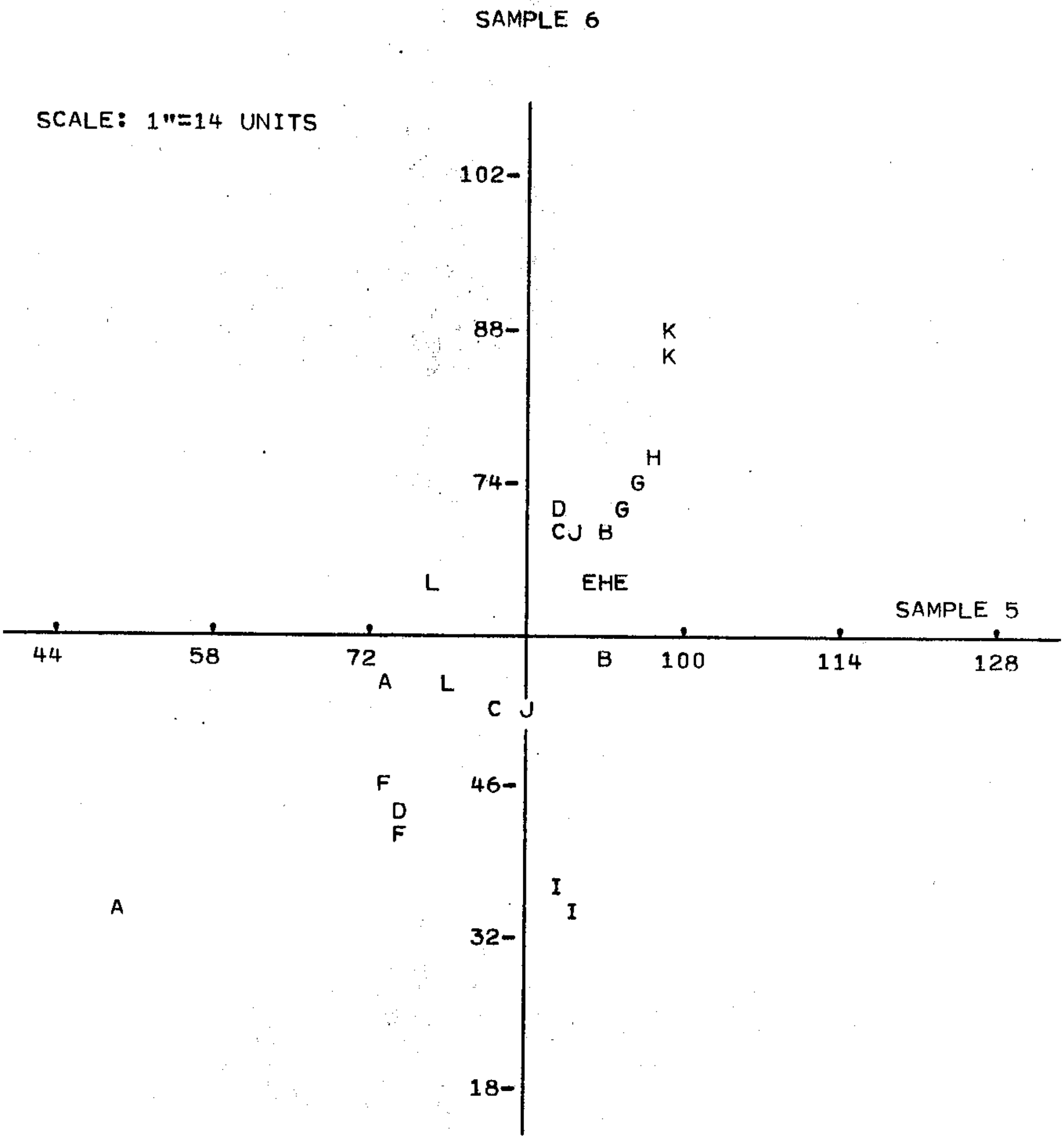
TRANSLAB CORRELATION PROGRAM

TEST METHOD: % CRUSHED PARTICLES   MATERIAL: AGG. BASE

DATE: 08/07/74

	SAMPLE 5	SAMPLE 6
MEAN	86.4	60.3
RANGE	50.0	54.1
STANDARD DEVIATION	11.39	15.42

PHI (RADIANS) = .992



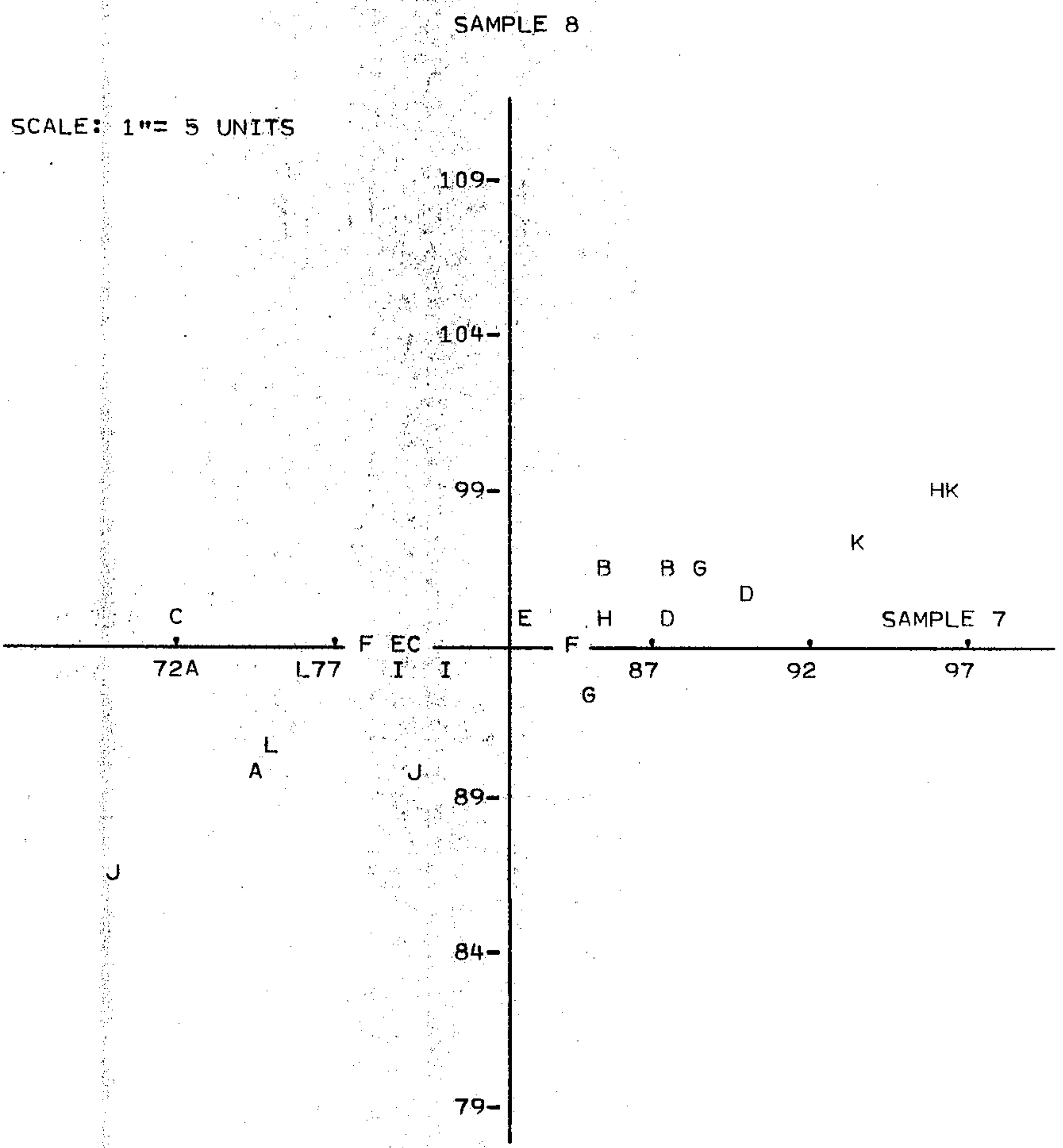
TRANSLAB CORRELATION PROGRAM

TEST METHOD: % CRUSHED PARTICLES (RET. #4) MATERIAL: AC
DATE: 08/07/74

	SAMPLE 7	SAMPLE 8
MEAN	82.4	93.8
RANGE	26.6	13.0
STANDARD DEVIATION	7.47	2.96

PHI (RADIANS) = .326

SCALE: 1"= 5 UNITS

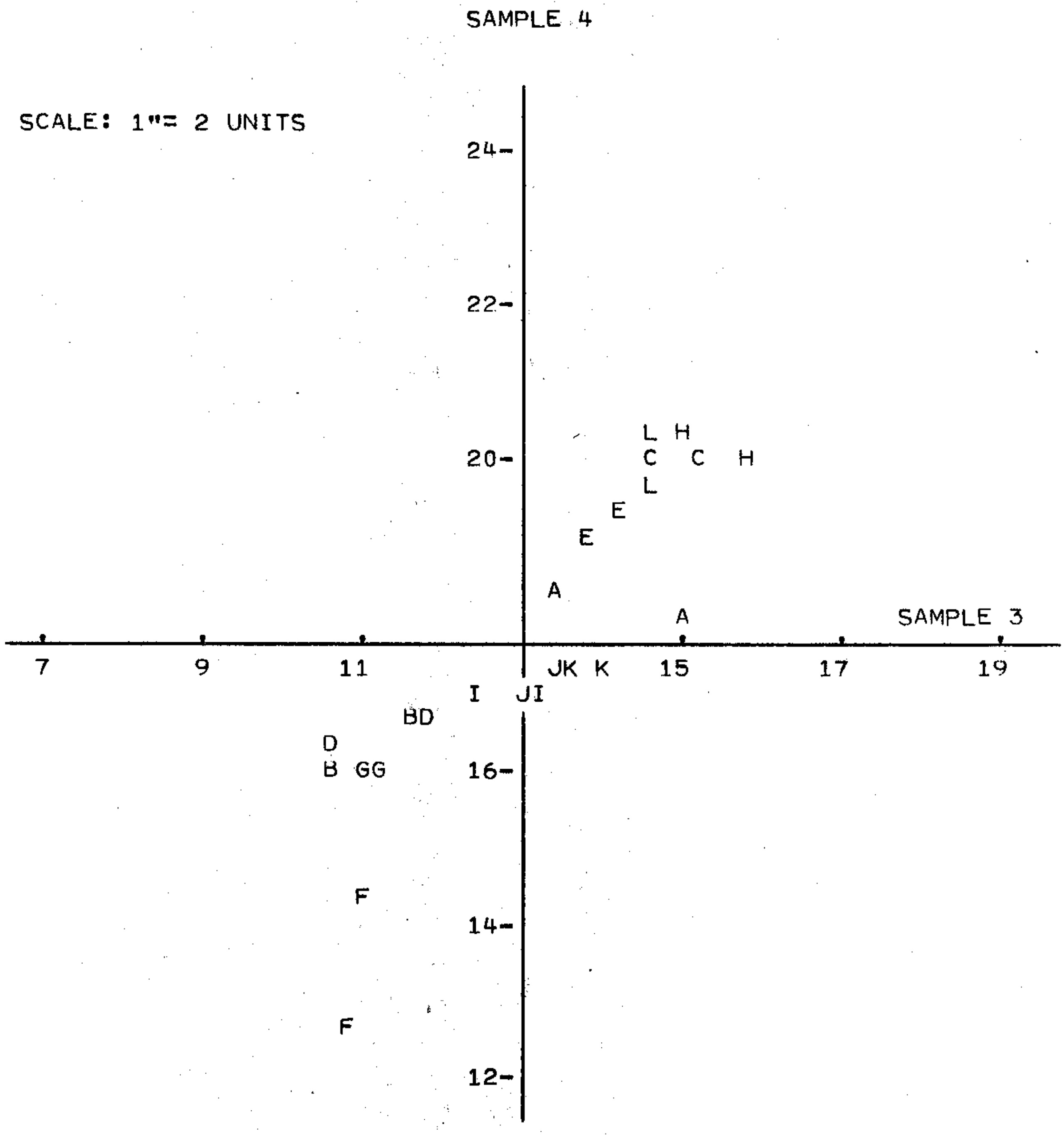


TRANSLAB CORRELATION PROGRAM

TEST METHOD: LA RATTLER (500 REV) MATERIAL: PCC
DATE: 08/08/74

	SAMPLE 3	SAMPLE 4
MEAN	13.1	17.7
RANGE	5.3	7.7
STANDARD DEVIATION	1.69	1.94

PHI (RADIANS) = .865



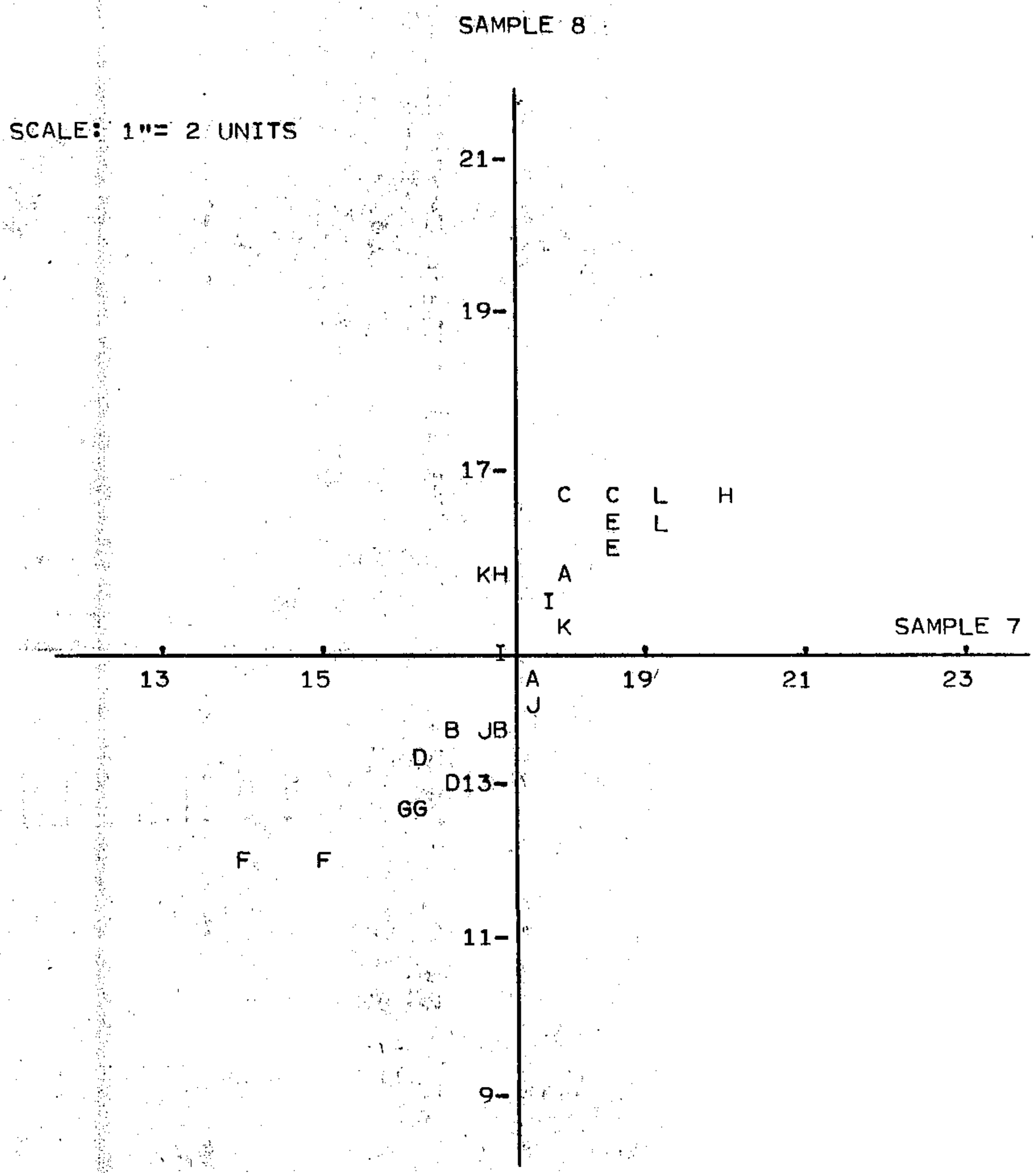
TRANSLAB CORRELATION PROGRAM

TEST METHOD: LA RATTLER(500 REV) MATERIAL: AC

DATE: 08/07/74

	SAMPLE 7	SAMPLE 8
MEAN	17.4	14.6
RANGE	6.0	4.7
STANDARD DEVIATION	1.35	1.56

PHI (RADIANS) = .863

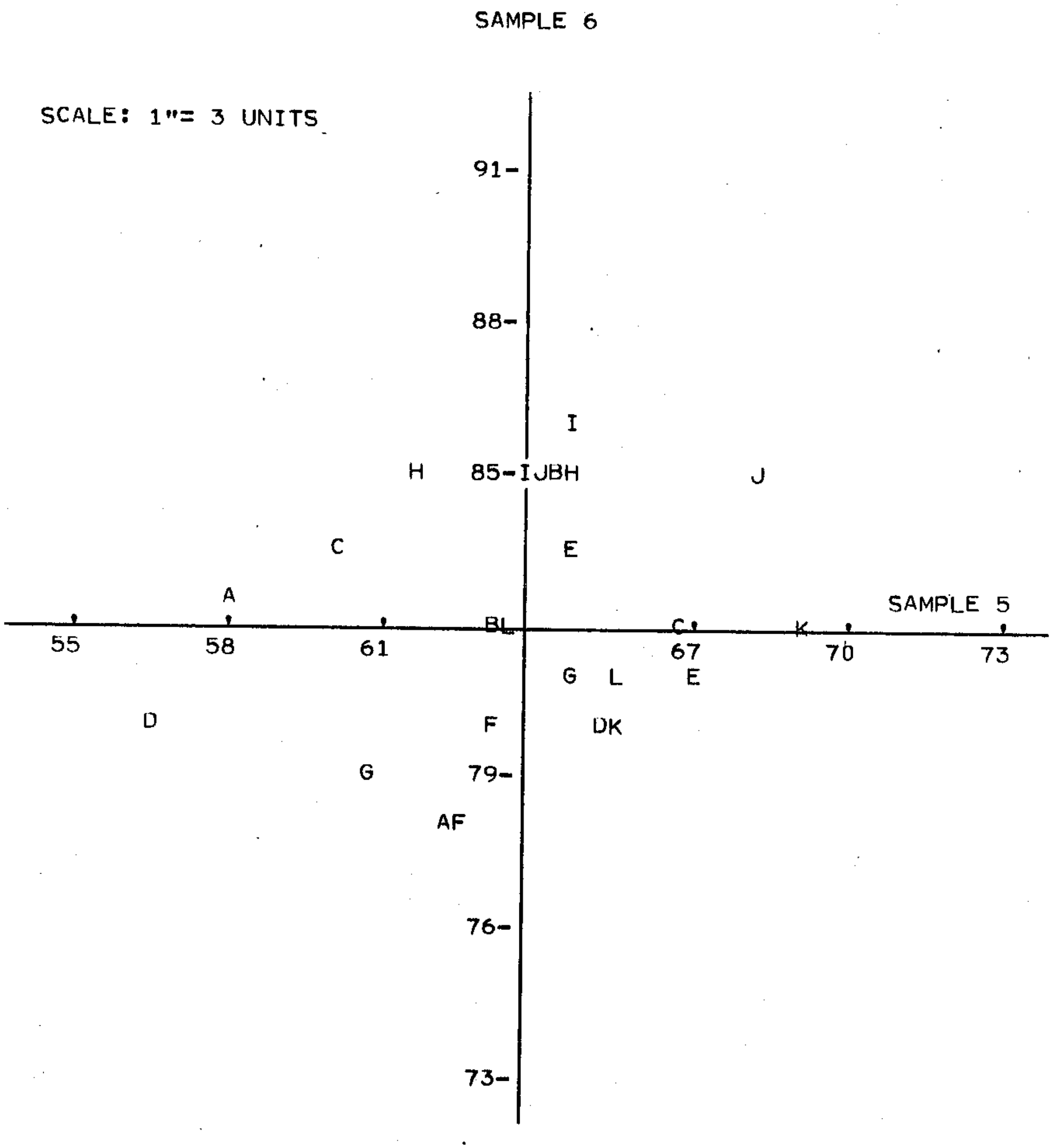


TRANSLAB CORRELATION PROGRAM

TEST METHOD: COARSE DURABILITY INDEX MATERIAL: AGG.BASE
DATE: 08/07/74

	SAMPLE 5	SAMPLE 6
MEAN	63.6	82.1
RANGE	12.5	8.0
STANDARD DEVIATION	2.91	2.42

PHI (RADIANS) = .400



TRANSLAB CORRELATION PROGRAM

TEST METHOD: FINE DURABILITY
DATE: 08/14/74

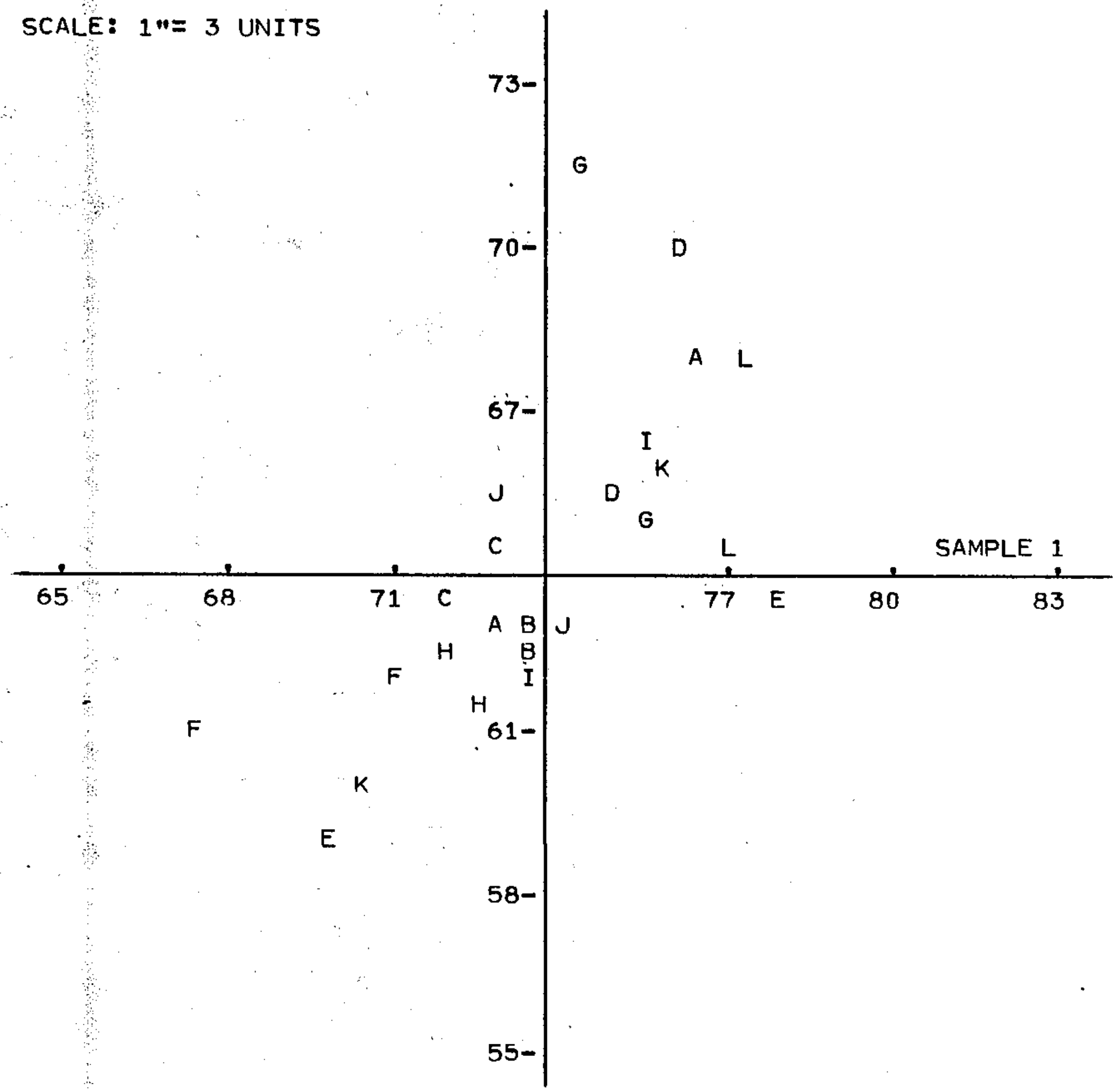
MATERIAL: PCC

	SAMPLE 1	SAMPLE 2
MEAN	73.8	64.2
RANGE	10.5	12.5
STANDARD DEVIATION	2.55	3.06

PHI (RADIANS) = .917

SAMPLE 2

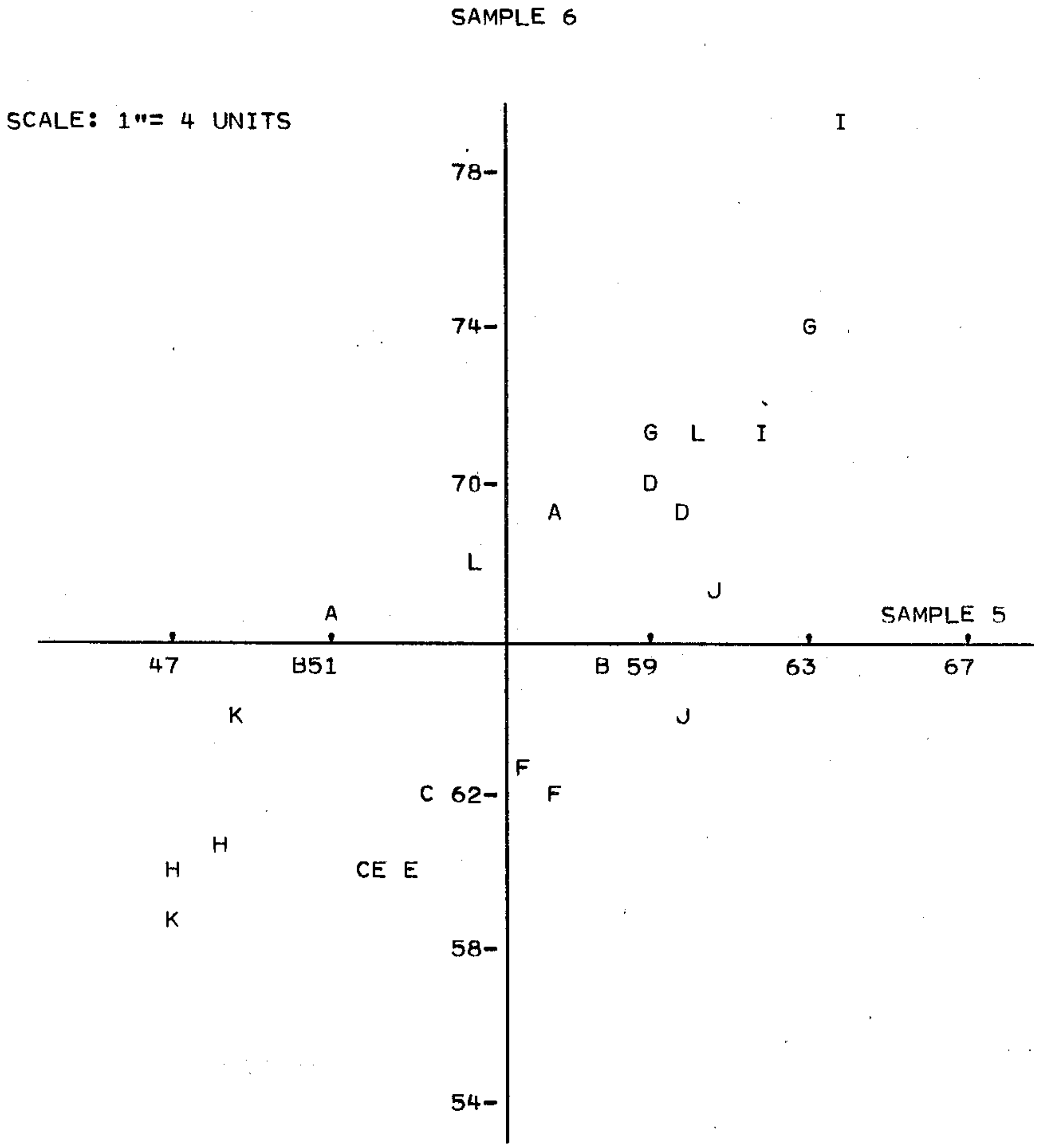
SCALE: 1"= 3 UNITS



TRANSLAB CORRELATION PROGRAM

TEST METHOD: FINE DURABILITY INDEX   MATERIAL: AGG. BASE
DATE: 08/07/74

	SAMPLE 5	SAMPLE 6
MEAN	55.3	65.9
RANGE	16.5	20.5
STANDARD DEVIATION	5.13	5.30
PHI (RADIANS) =	.806	



TRANSLAB CORRELATION PROGRAM

TEST METHOD: R-VALUE
DATE: 08/07/74

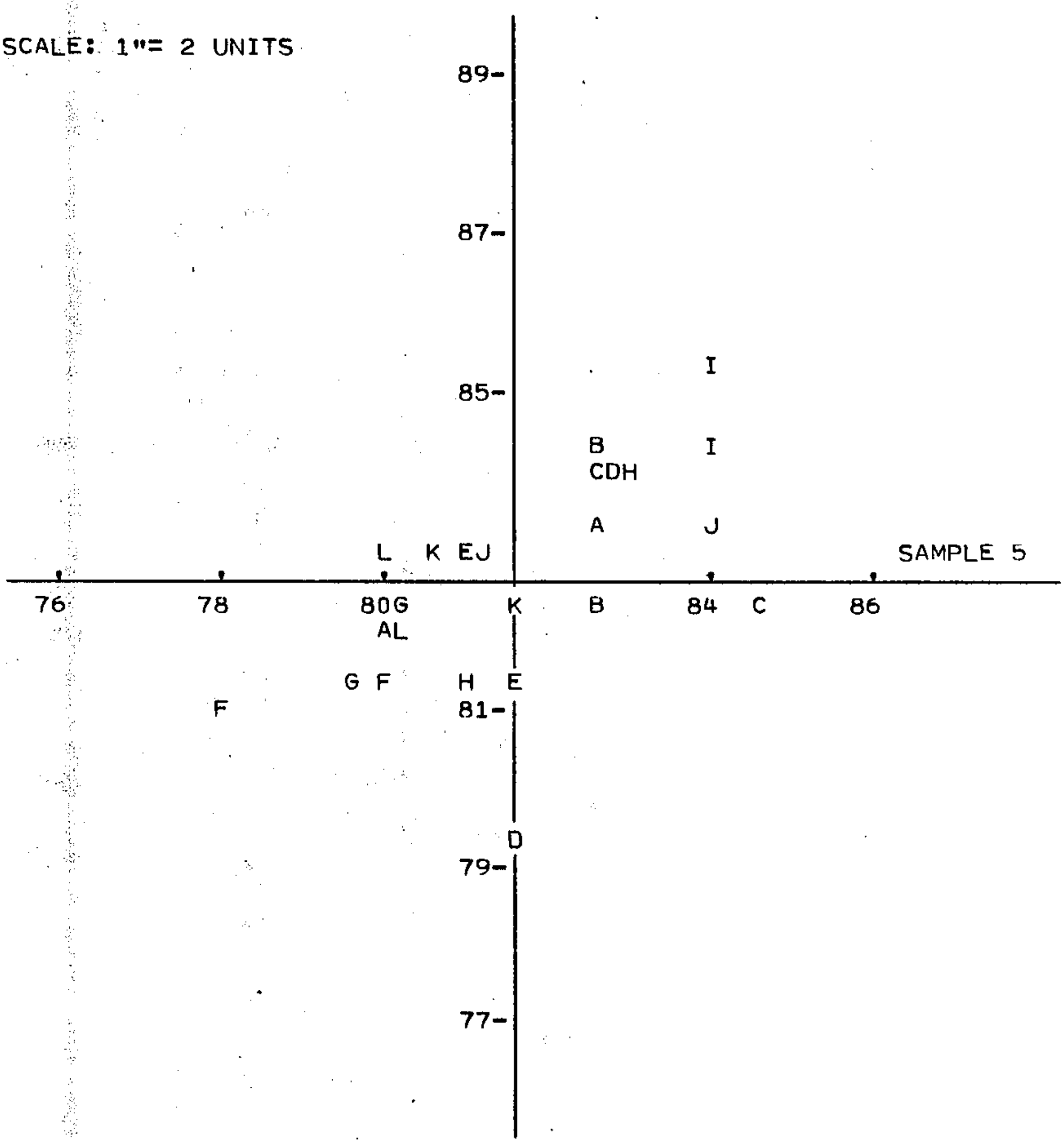
MATERIAL: AGG. BASE

	SAMPLE 5	SAMPLE 6
MEAN	81.6	82.8
RANGE	6.5	6.0
STANDARD DEVIATION	1.67	1.33

PHI (RADIANS) = .604

SAMPLE 6

SCALE: 1"= 2 UNITS

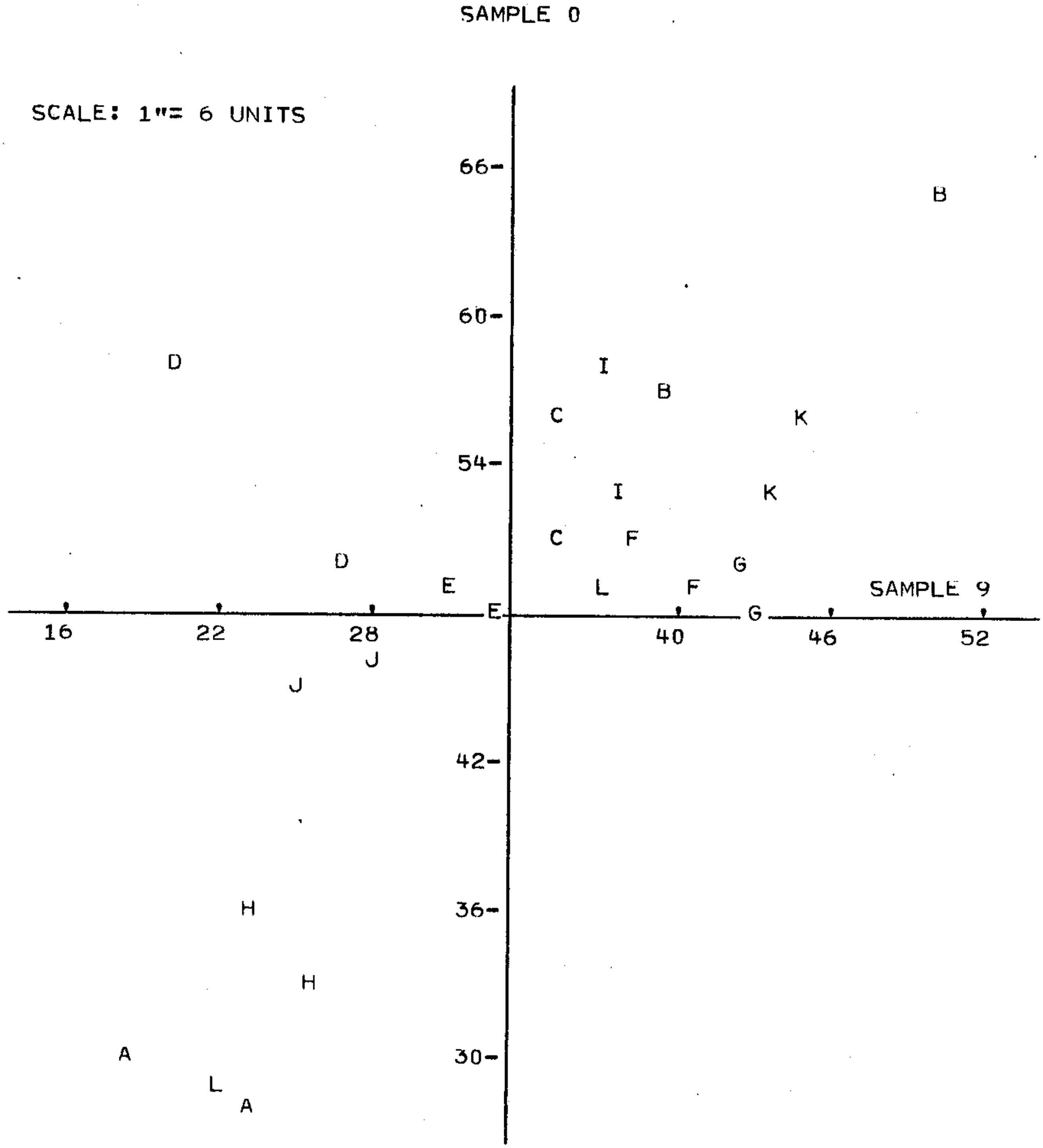


TRANSLAB CORRELATION PROGRAM

TEST METHOD: R-VALUE
DATE: 08/07/74

MATERIAL: AGG. SUBBASE

	SAMPLE 9	SAMPLE 0
MEAN	33.7	48.0
RANGE	31.7	38.0
STANDARD DEVIATION	8.85	10.11
PHI (RADIANS) =	.879	



TRANSLAB CORRELATION PROGRAM

TEST METHOD: SIEVE ANALYSIS (3/4" SCREEN) MATERIAL: AC

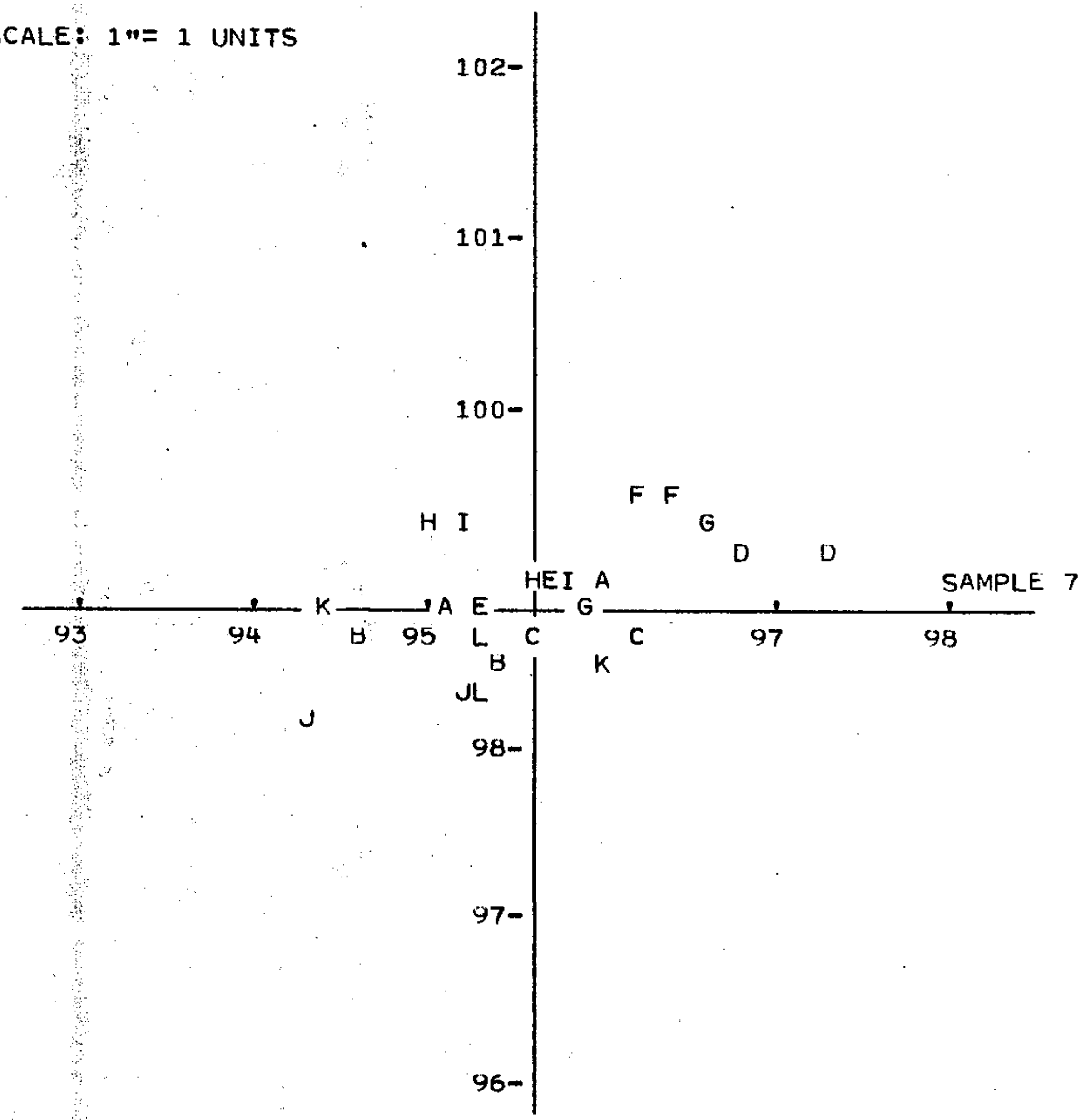
DATE: 08/06/74

	SAMPLE 7	SAMPLE 8
MEAN	95.6	98.9
RANGE	3.0	1.2
STANDARD DEVIATION	.73	.37

PHI (RADIANS) = .312

SAMPLE 8

SCALE: 1"= 1 UNITS



TRANSLAB CORRELATION PROGRAM

TEST METHOD: SIEVE ANALYSIS(1/2" SCREEN)   MATERIAL: PCC

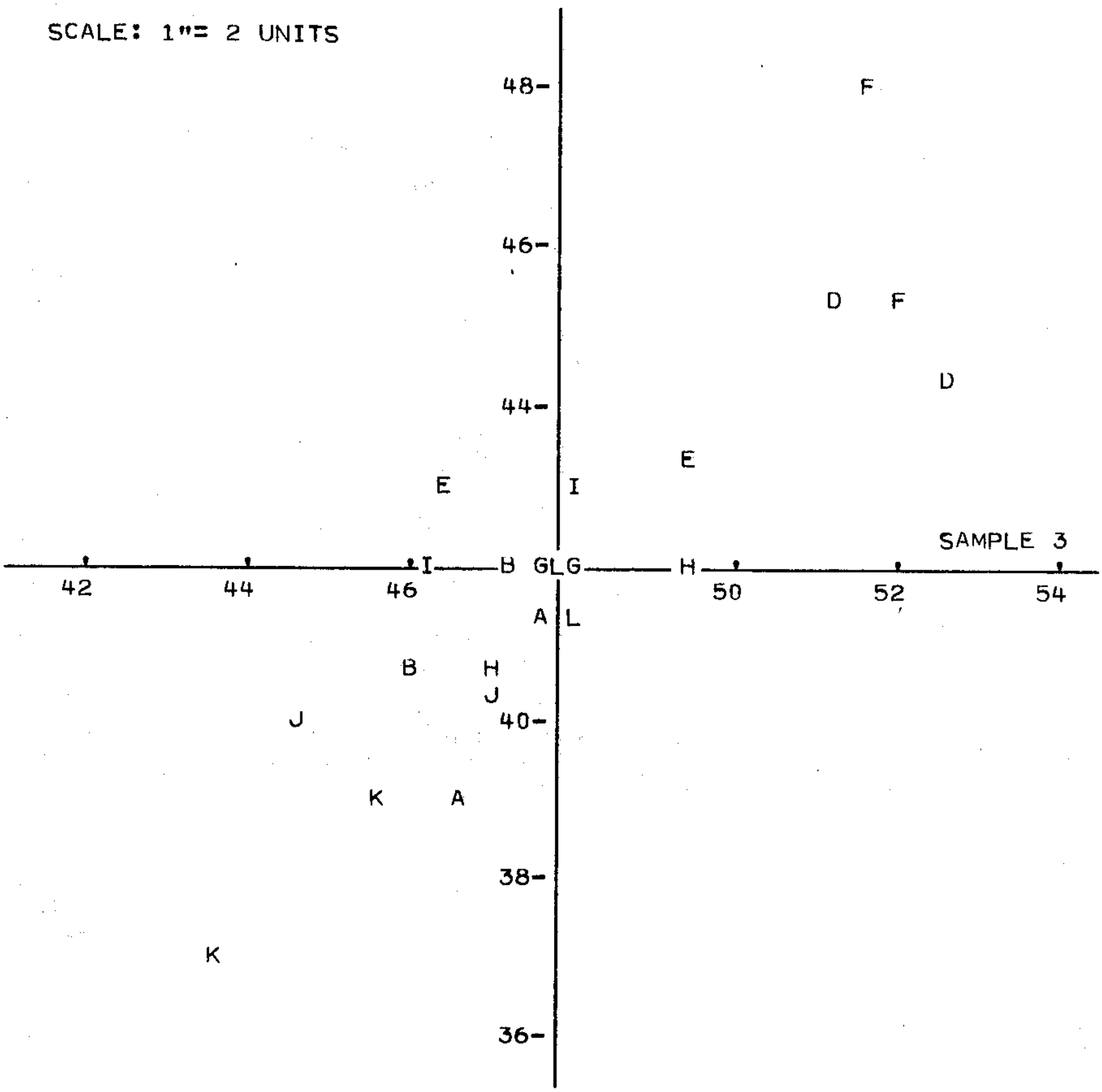
DATE: 08/07/74

	SAMPLE 3	SAMPLE 4
MEAN	47.8	42.1
RANGE	9.0	11.0
STANDARD DEVIATION	2.36	2.42

PHI (RADIANS) = .800

SAMPLE 4

SCALE: 1"= 2 UNITS



TRANSLAB CORRELATION PROGRAM

TEST METHOD: SIEVE ANALYSIS(3/8" SCREEN)   MATERIAL: AGG. SUBBASE

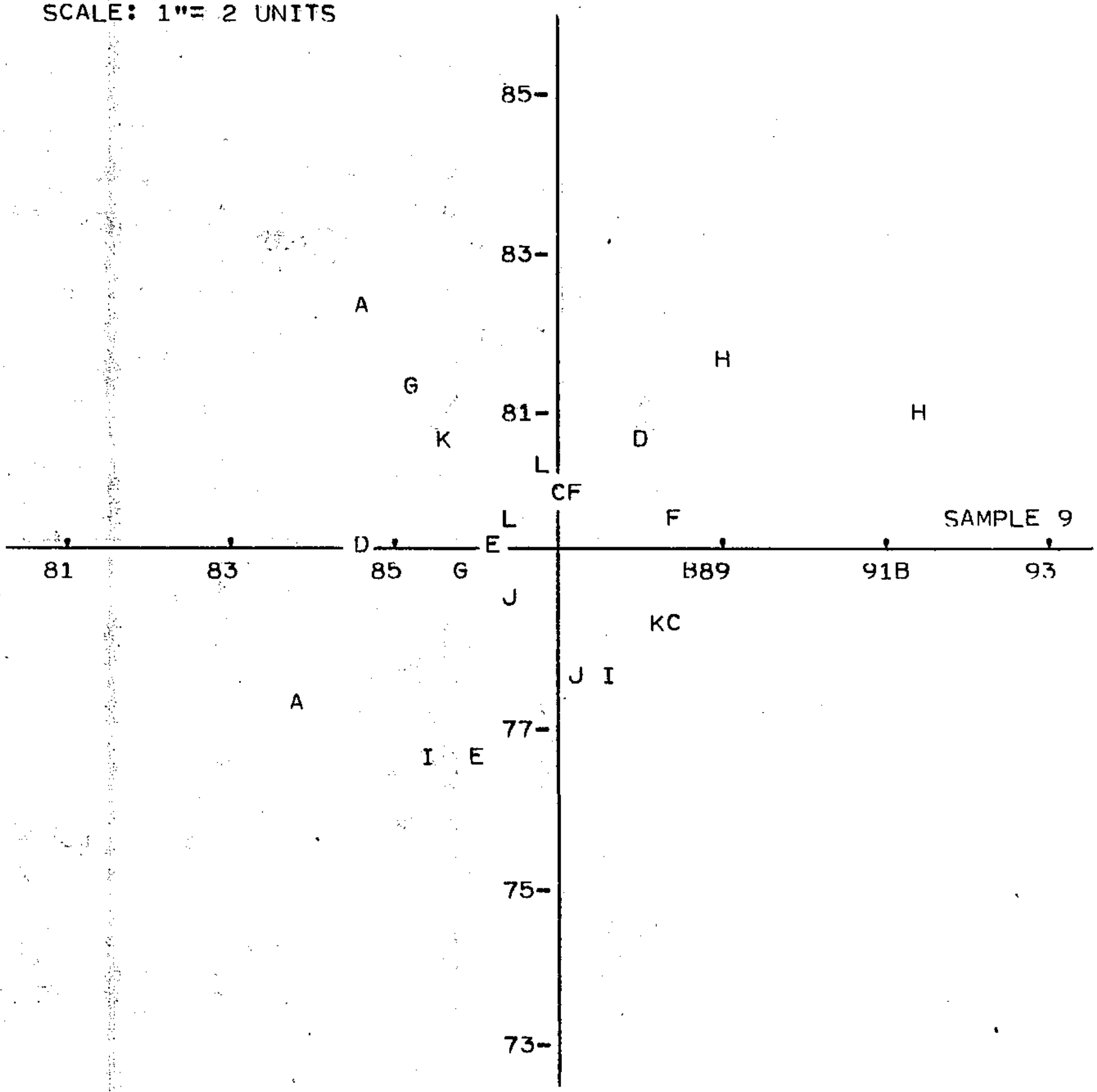
DATE: 08/07/74

	SAMPLE 9	SAMPLE 0
MEAN	87.1	79.2
RANGE	7.7	5.7
STANDARD DEVIATION	1.92	1.52

PHI (RADIANS) = .256

SAMPLE 0

SCALE: 1"= 2 UNITS



TRANSLAB CORRELATION PROGRAM

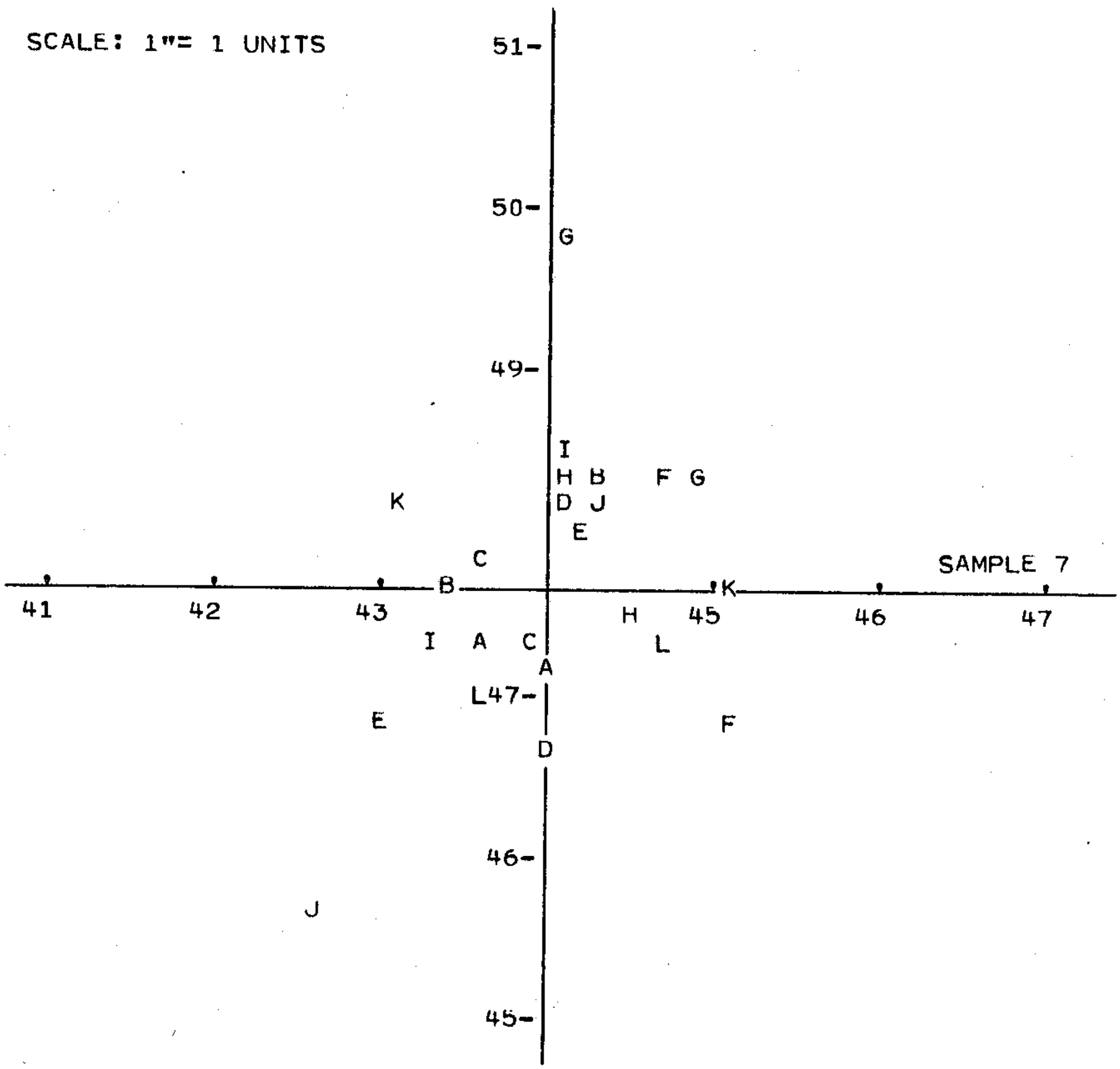
TEST METHOD: SIEVE ANALYSIS(#4 SCREEN)   MATERIAL: AC

DATE: 08/06/74

	SAMPLE 7	SAMPLE 8
MEAN	44.0	47.6
RANGE	2.5	4.0
STANDARD DEVIATION	.64	.81

PHI (RADIANS) = 1.067

SAMPLE 8



TRANSLAB CORRELATION PROGRAM

TEST METHOD: SIEVE ANALYSIS (#8 SCREEN) MATERIAL: AGG. BASE

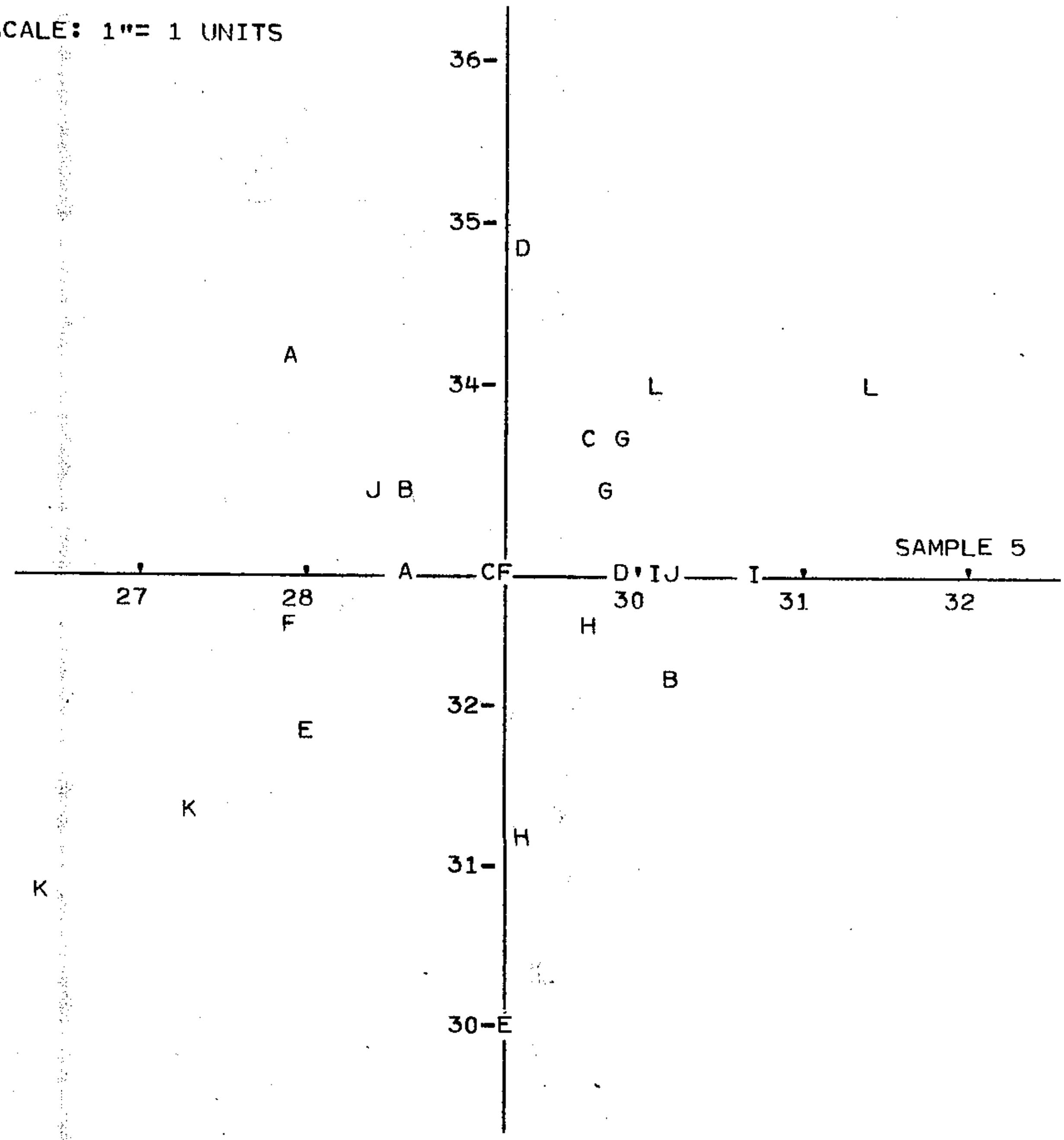
DATE: 08/07/74

	SAMPLE 5	SAMPLE 6
MEAN	29.2	32.9
RANGE	5.0	4.8
STANDARD DEVIATION	1.15	1.13

PHI (RADIANS) = .767

SAMPLE 6

SCALE: 1"= 1 UNITS



TRANSLAB CORRELATION PROGRAM

TEST METHOD: SIEVE ANALYSIS(#16 SCREEN)   MATERIAL: AGG. SUBBASE

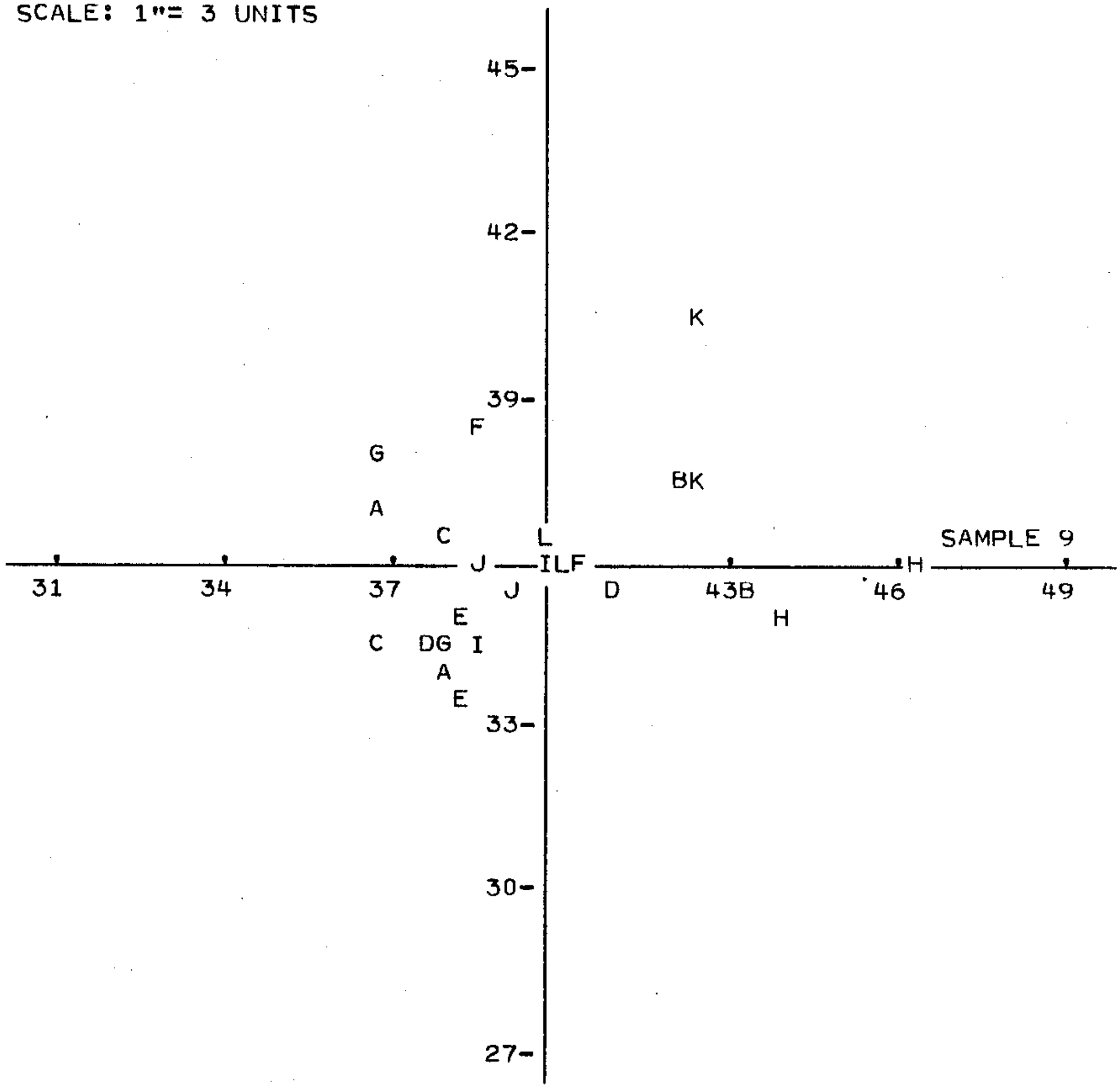
DATE: 08/07/74

	SAMPLE 9	SAMPLE 0
MEAN	39.6	35.8
RANGE	9.7	7.4
STANDARD DEVIATION	2.50	1.62

PHI (RADIANS) = .227

SAMPLE 0

SCALE: 1"= 3 UNITS



TRANSLAB CORRELATION PROGRAM

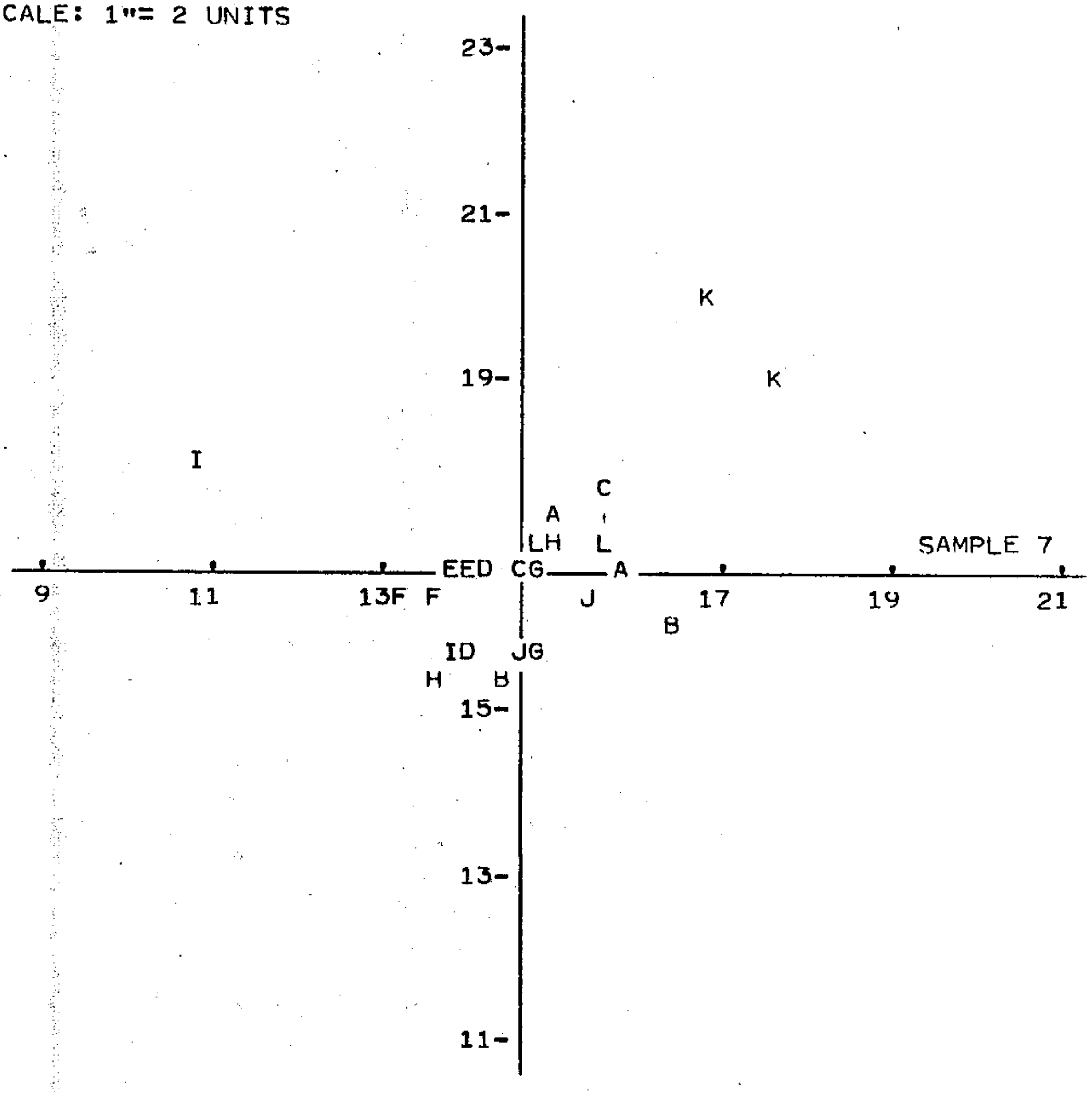
TEST METHOD: SIEVE ANALYSIS(#30 SCREEN) MATERIAL: AC
DATE: 08/06/74

	SAMPLE 7	SAMPLE 8
MEAN	14.6	16.7
RANGE	6.6	5.0
STANDARD DEVIATION	1.34	1.13

PHI (RADIANS) = .575

SAMPLE 8

SCALE: 1"= 2 UNITS



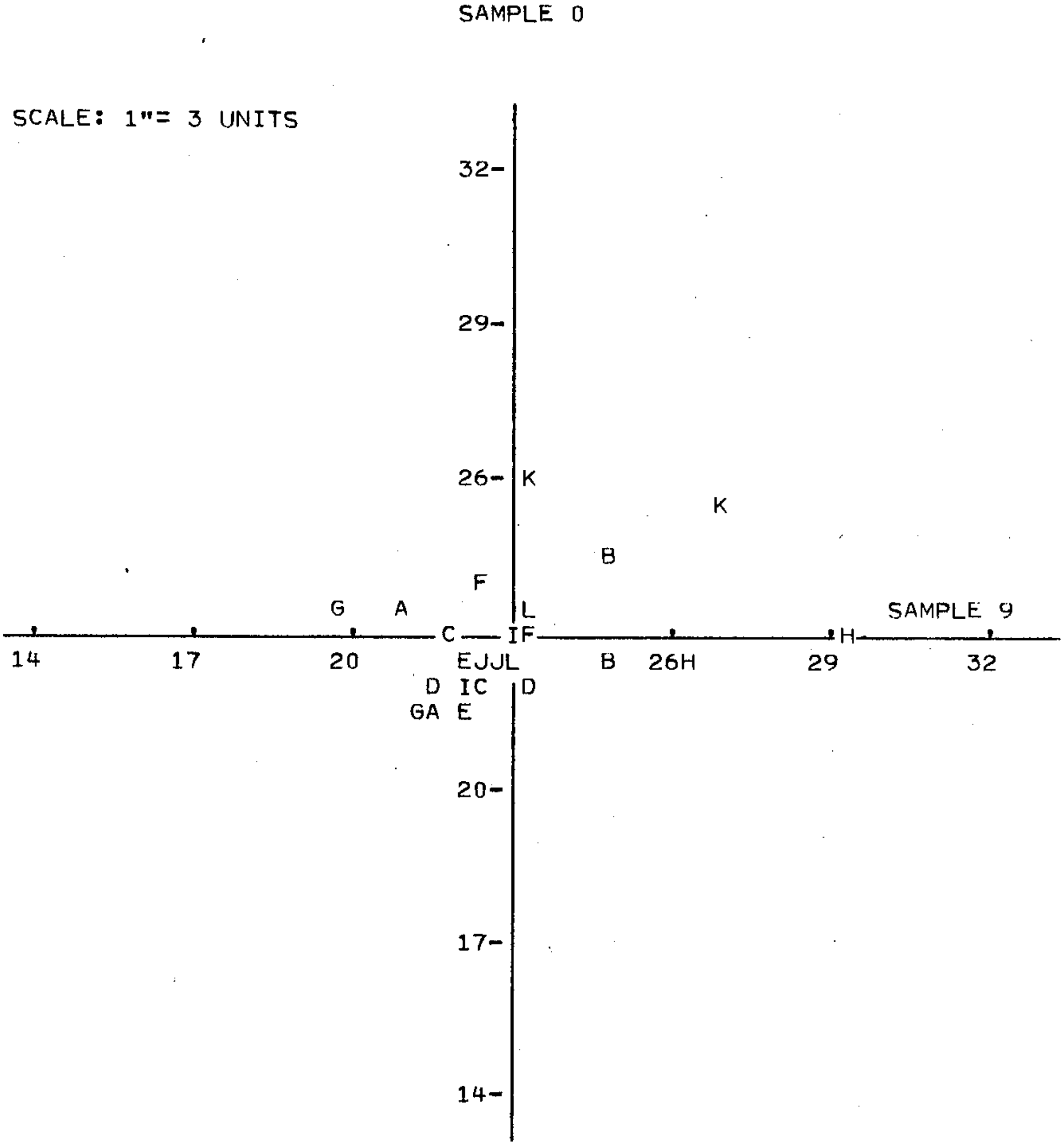
TRANSLAB CORRELATION PROGRAM

TEST METHOD: SIEVE ANALYSIS(#50 SCREEN)   MATERIAL: AGG. SUBBASE

DATE: 08/07/74

	SAMPLE 9	SAMPLE 0
MEAN	23.1	23.0
RANGE	9.4	4.9
STANDARD DEVIATION	2.06	1.20

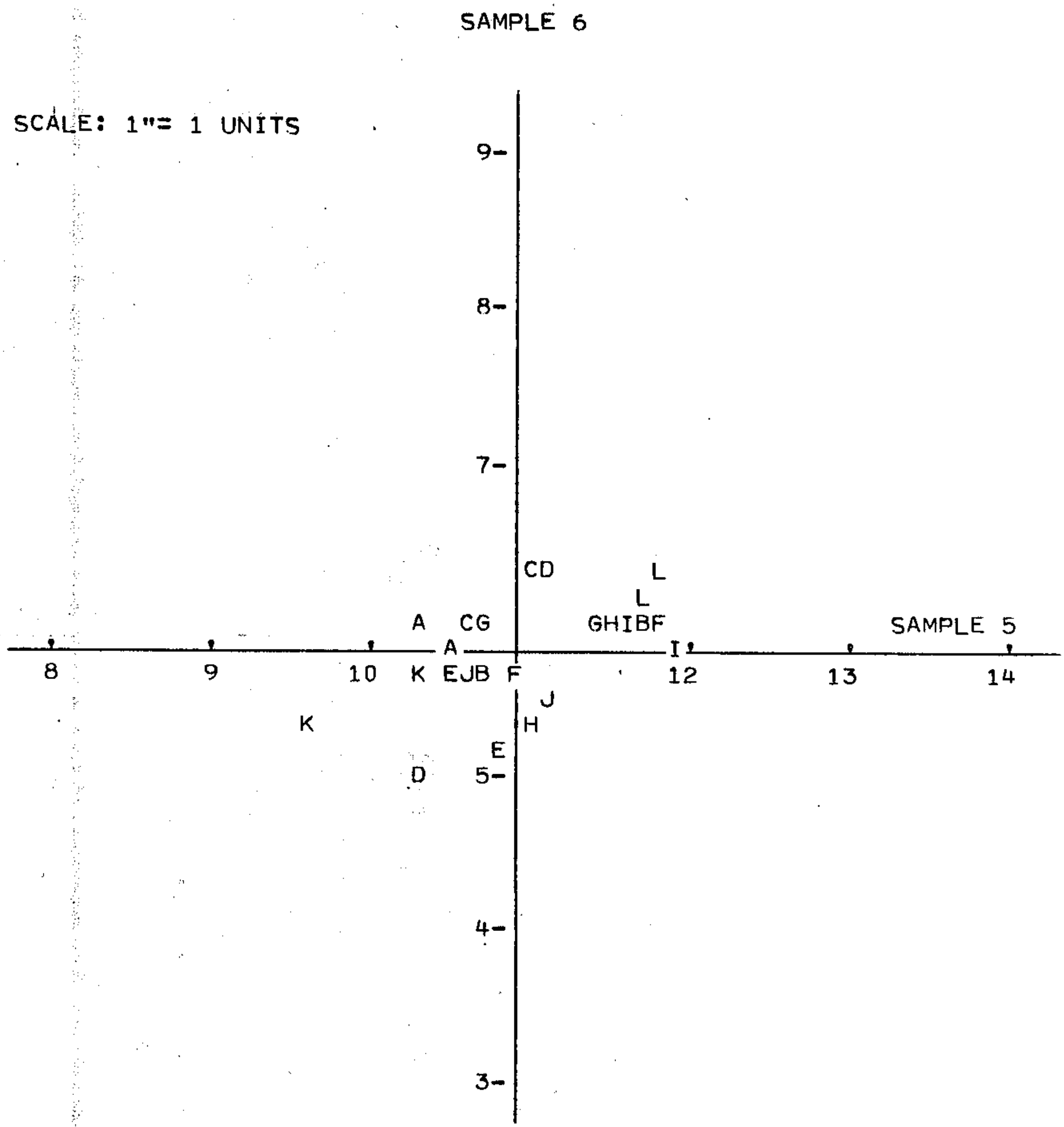
PHI (RADIANS) = .253



TRANSLAB CORRELATION PROGRAM

TEST METHOD: SIEVE ANALYSIS (#100 SCREEN)   MATERIAL: AGG. BASE
DATE: 08/07/74

	SAMPLE 5	SAMPLE 6
MEAN	10.9	5.8
RANGE	2.3	1.4
STANDARD DEVIATION	.60	.37
PHI (RADIANS) =	.412	



TRANSLAB CORRELATION PROGRAM

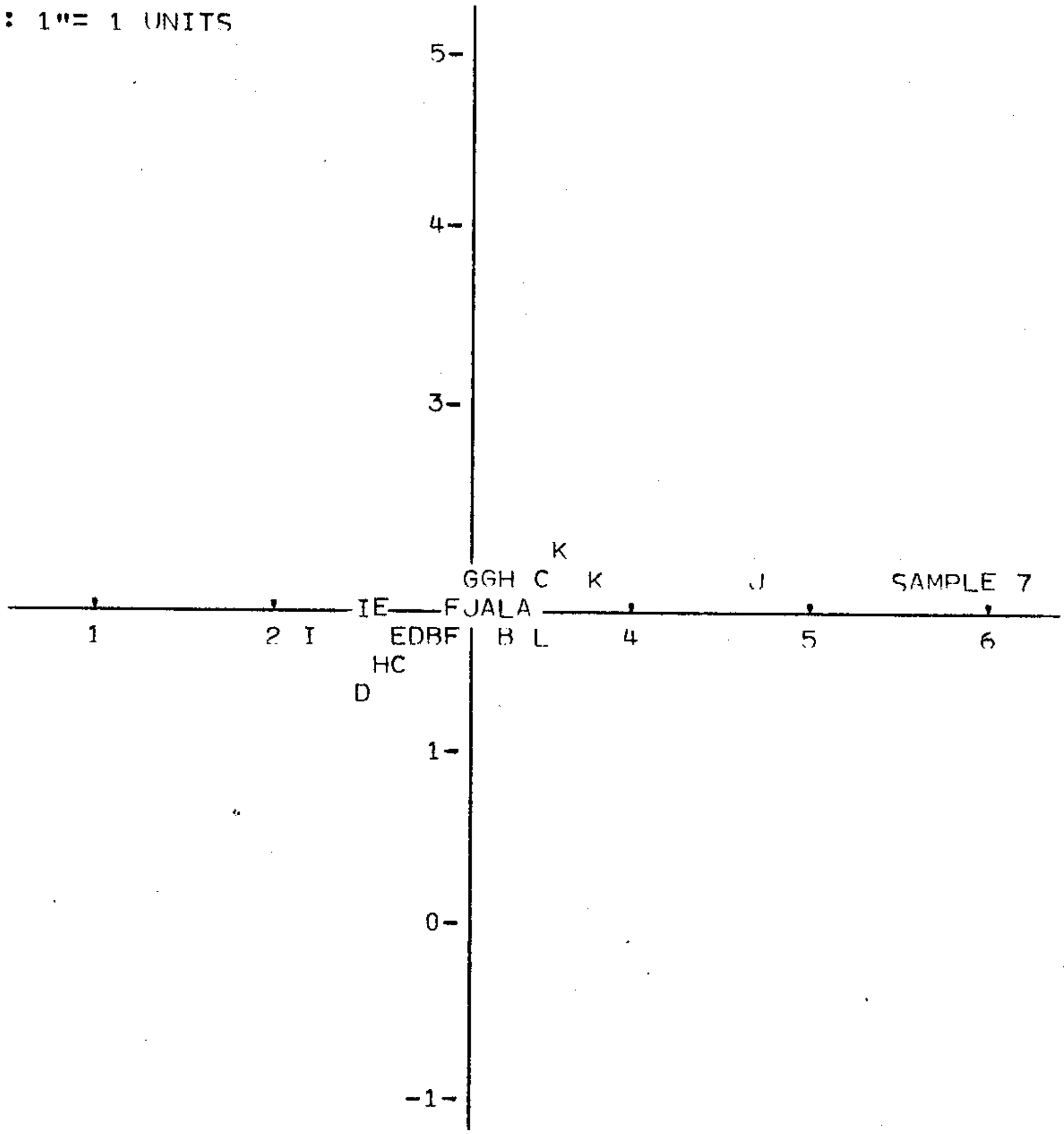
TEST METHOD: SIEVE ANALYSIS(#200 SCREEN)   MATERIAL: AC
DATE: 08/07/74

	SAMPLE 7	SAMPLE 8
MEAN	3.1	1.8
RANGE	2.5	1.0
STANDARD DEVIATION	.52	.22

PHI (RADIANS) = .282

SAMPLE 8

SCALE: 1"= 1 UNITS



APPENDIX C

LABORATORY RANKING

Evaluating the performance of individual laboratories is an important part of a correlation program since systematic errors often stem from discrepant laboratories. Scatter diagrams can only evaluate laboratory performance for two samples at a time. However, a ranking system can evaluate laboratory performance for any number of samples.

By re-examining Figure 3 it can be seen that each laboratory will have 4 test results for each sample. These 4 results are averaged and their standard deviation (sigma) calculated. This yields 12 averages and 12 sigmas for each sample.

The laboratory averages and standard deviations are ranked from lowest to highest by the computer. A rank of 1.0 indicates the lowest result for a particular sample. Conversely, a rank of 12.0 indicates the highest result. When results are identical the ranks involved are averaged and this average rank assigned to the respective laboratories. This explains the occurrence of ranks incremented by 0.5.

Once the ranks are assigned for each sample, a rank sum is calculated for each laboratory. Results are then recorded by laboratory from lowest to highest rank sum. Simultaneously, the columnar arrangement of results is recorded to read from the lowest sample average to the highest. This completed rearrangement is the form in which results appear on the output.

The ranking summary and analysis is presented in two separate blocks. The first block ranks the mean or average results obtained by laboratories while the second ranks the within laboratory standard deviations. The rank sum corresponding to each laboratory is shown, in addition to the Kendall Rank Correlation Coefficient. This coefficient is a measure of increases or decreases in rank standing corresponding to increases in the sample average. There were not enough samples in the pilot study for this statistic to be significant, however.

Both the rank sum and Kendall Coefficient are marked by an asterisk if significant at the 95% level. This means there is only a 5% chance that the marked value is caused by random fluctuations. If the trends indicated by the pilot study are correct and results from more samples were available, more laboratories would receive these asterisks. However, because results from only 4 samples were generally available for each test method, fewer significantly different laboratories were able to be detected.

LABORATORY RANKING SUMMARY - NONPARAMETRIC ANALYSIS

% CRUSHED PARTICLES (RET. #4)

MEAN RANKS:

LAB CODE	SAMPLE 6	SAMPLE 7	SAMPLE 5	SAMPLE 8	RANK SUM	KENDALL RANK CORRELATION COEFFICIENT
A	3.0	1.0	1.0	2.0	7.0 *	-.17
L	5.0	3.0	3.0	3.0	14.0	-.55
J	7.0	2.0	6.0	1.0	16.0	-.67
F	2.0	7.0	2.0	5.0	16.0	.17
I	1.0	5.0	7.0	4.0	17.0	.33
C	8.0	4.0	5.0	8.0	25.0	.17
E	6.0	6.0	8.0	6.0	26.0	.18
D	4.0	10.0	4.0	9.0	27.0	.17
B	9.0	8.0	9.0	10.0	36.0	.50
G	11.0	9.0	10.5	7.0	37.5	-.67
H	10.0	11.0	10.5	11.0	42.5	.50
K	12.0	12.0	12.0	12.0	48.0 *	.00
				MEAN SCORE	26.0	

SIGMA RANKS:

LAB CODE	SAMPLE 6	SAMPLE 7	SAMPLE 5	SAMPLE 8	RANK SUM	KENDALL RANK CORRELATION COEFFICIENT
B	6.0	1.0	1.0	1.0	9.0	-.50
K	3.0	4.0	2.0	4.0	13.0	.18
I	2.0	2.0	5.0	5.0	14.0	.67
G	1.0	5.0	3.0	9.5	18.5	.67
E	4.0	6.0	6.0	6.0	22.0	.50
F	5.0	8.0	8.0	3.0	24.0	-.17
D	12.0	3.0	11.0	2.0	28.0	-.73
J	10.0	10.0	4.0	9.5	33.5	-.50
C	9.0	11.0	7.0	7.0	34.0	-.50
L	7.0	7.0	10.0	12.0	36.0	.83
A	11.0	9.0	12.0	8.0	40.0	-.33
H	8.0	12.0	9.0	11.0	40.0	.58
				MEAN SCORE	26.0	

* - EXCEEDS CRITICAL LIMITS AT APPROXIMATE 95% LEVEL.

LA RATTLER (500 REV)

MEAN RANKS:

LAB CODE	SAMPLE 3	SAMPLE 8	SAMPLE 7	SAMPLE 4	RANK SUM		KENDALL RANK CORRELATION COEFFICIENT
F	1.0	1.0	1.0	1.0	4.0	*	.00
G	2.0	2.0	2.0	2.0	8.0		.00
B	3.0	4.0	4.0	3.0	14.0		.00
D	4.0	3.0	3.0	4.0	14.0		.00
J	6.0	5.0	5.0	6.0	22.0		.00
I	5.0	6.0	6.0	5.0	22.0		.00
K	7.0	8.0	7.0	7.0	29.0		-.18
A	9.0	7.0	8.0	8.0	32.0		-.17
E	8.0	10.0	11.0	9.0	38.0		.33
C	11.0	12.0	9.0	10.0	42.0		-.33
H	12.0	9.0	10.0	12.0	43.0		.17
L	10.0	11.0	12.0	11.0	44.0		.50
				MEAN SCORE	26.0		

SIGMA RANKS:

LAB CODE	SAMPLE 3	SAMPLE 8	SAMPLE 7	SAMPLE 4	RANK SUM	KENDALL RANK CORRELATION COEFFICIENT
G	1.0	5.0	5.0	1.5	12.5	.29
B	7.0	3.0	4.0	4.0	18.0	-.29
L	3.0	4.0	1.0	10.0	18.0	.33
C	6.0	6.0	8.0	3.0	23.0	-.17
D	8.0	2.0	6.0	8.0	24.0	.17
E	2.0	10.0	2.0	11.0	25.0	.50
I	5.0	9.0	10.0	1.5	25.5	.00
F	4.0	1.0	9.0	12.0	26.0	.67
A	11.5	11.0	3.0	5.5	31.0	-.67
J	11.5	7.5	7.0	5.5	31.5	-1.00
K	9.0	7.5	11.0	9.0	36.5	.17
H	10.0	12.0	12.0	7.0	41.0	-.17
				MEAN SCORE	26.0	

* - EXCEEDS CRITICAL LIMITS AT APPROXIMATE 95% LEVEL.

FINE DURABILITY

MEAN RANKS:

LAB CODE	SAMPLE 5	SAMPLE 2	SAMPLE 6	SAMPLE 1	RANK SUM	KENDALL RANK CORRELATION COEFFICIENT
H	1.0	3.0	2.0	2.0	8.0	.17
E	4.0	1.0	1.0	7.0	13.0	.17
C	3.0	6.0	3.0	3.0	15.0	-.18
F	7.0	2.0	5.0	1.0	15.0	-.67
K	2.0	5.0	4.0	4.0	15.0	.17
B	5.5	4.0	6.0	5.5	21.0	.17
J	10.0	7.5	7.0	5.5	30.0	-1.00
A	5.5	9.0	8.0	9.0	31.5	.50
I	12.0	7.5	12.0	8.0	39.5	-.17
L	8.0	10.0	9.5	12.0	39.5	.67
D	9.0	11.0	9.5	11.0	40.5	.50
G	11.0	12.0	11.0	10.0	44.0	-.50
				MEAN SCORE	26.0	

SIGMA RANKS:

LAB CODE	SAMPLE 5	SAMPLE 2	SAMPLE 6	SAMPLE 1	RANK SUM	KENDALL RANK CORRELATION COEFFICIENT
C	3.0	2.0	5.0	2.5	12.5	.00
F	2.0	3.0	2.5	9.0	16.5	.67
H	10.0	4.0	4.0	1.0	19.0	-.91
B	11.0	1.0	6.0	2.5	20.5	-.33
E	1.0	7.0	1.0	12.0	21.0	.50
J	4.0	5.0	7.0	6.0	22.0	.67
D	8.0	8.0	2.5	4.0	22.5	-.50
G	7.0	11.0	8.0	5.0	31.0	-.33
L	9.0	6.0	9.0	7.0	31.0	-.17
I	6.0	9.0	12.0	8.0	35.0	.33
K	5.0	12.0	11.0	11.0	39.0	.17
A	12.0	10.0	10.0	10.0	42.0	-.50
				MEAN SCORE	26.0	

* - EXCEEDS CRITICAL LIMITS AT APPROXIMATE 95% LEVEL.

R-VALUE

MEAN RANKS:

LAB CODE	SAMPLE 9	SAMPLE 0	SAMPLE 5	SAMPLE 6	RANK SUM	KENDALL RANK CORRELATION COEFFICIENT
A	1.0	1.0	5.5	8.0	15.5	.83
L	5.0	3.0	3.0	5.0	16.0	.00
F	9.0	7.0	1.0	1.0	18.0	-.83
H	3.0	2.0	7.5	6.5	19.0	.33
E	6.0	5.0	5.5	4.0	20.5	-.67
D	2.0	9.0	7.5	2.0	20.5	-.17
G	10.0	6.0	2.0	3.0	21.0	-.67
J	4.0	4.0	9.5	9.5	27.0	.67
K	11.0	10.0	4.0	6.5	31.5	-.67
C	7.0	8.0	11.0	9.5	35.5	.67
I	8.0	11.0	12.0	12.0	43.0	.83
B	12.0	12.0	9.5	11.0	44.5	-.50

MEAN SCORE 26.0

SIGMA RANKS:

LAB CODE	SAMPLE 9	SAMPLE 0	SAMPLE 5	SAMPLE 6	RANK SUM	KENDALL RANK CORRELATION COEFFICIENT
E	2.0	5.5	2.5	9.0	19.0	.67
A	6.0	2.0	11.0	1.0	20.0	-.33
C	5.0	7.0	7.0	3.0	22.0	-.17
J	4.0	1.0	12.0	5.0	22.0	.33
H	3.0	4.0	6.0	10.0	23.0	1.00
K	1.0	11.0	9.0	3.0	24.0	.00
I	7.0	5.5	5.0	8.0	25.5	.00
F	12.0	3.0	9.0	3.0	27.0	-.50
B	9.0	8.0	4.0	6.5	27.5	-.67
L	10.0	12.0	1.0	6.5	29.5	-.33
G	11.0	9.0	2.5	11.0	33.5	-.17
D	8.0	10.0	9.0	12.0	39.0	.67

MEAN SCORE 26.0

* - EXCEEDS CRITICAL LIMITS AT APPROXIMATE 95% LEVEL.